Chapter 6: Everglades Research and Evaluation

Edited by Fred Sklar and Thomas Dreschel

SUMMARY

The studies and findings discussed in this chapter are presented within four main fields: (1) wildlife ecology, (2) plant ecology, (3) ecosystem ecology, and (4) landscape. Programs of study are based on the short-term operational needs and long-term restoration goals of the South Florida Water Management District (SFWMD or District), including large-scale and regional hydrologic needs in relation to regulation schedules, permitting, Everglades Forever Act (Section 373.4592, Florida Statutes) mandates, and the Comprehensive Everglades Restoration Plan. This chapter summarizes Water Year 2012 (WY2012) (May 1, 2011–April 30, 2012) hydrology in the Everglades Protection Area (EPA), followed by an overview of key Everglades studies on wildlife, plants, ecosystem, and landscapes (**Table 6-1**).

HYDROLOGY

While regional dry conditions persisted in WY2012 due to the continuing La Niña, severe drought in the Everglades was averted because of heavy rainfall in October 2011 (see Chapter 2 of this volume). As a result, overall rainfall in the EPA was substantially greater than last year, especially in Water Conservation Area 3 (WCA-3) (WY2012 rainfall was 14.2 inches more than WY2011). These conditions were positive for the Everglades and may indicate that local meteorological influence on rainfall patterns may be beneficial despite global circulation patterns that would point toward drier conditions for South Florida. There is a need for more research on the role of the Everglades as a climatic buffer. The general hydropattern for WY2012 across most of the Everglades was (1) a significant delay in the start of the wet season, (2) followed by a quick rise to an average water depth of about 2 feet (ft), (3) then followed by a recession rate very conducive for wading bird foraging. However, late dry season (April–May) water depths did not reach optimal foraging depths of 0.2-0.5 ft for very long, possibly influencing, in part, a rather unsuccessful nesting season (see the *Wildlife Ecology* section of this chapter).

Hydrologic patterns in Florida Bay and southern Everglades National Park (ENP or Park) were similar to those in the upper marshes. During the beginning of WY2012, conditions in Florida Bay and the mangrove transition zone were characterized by high salinities and low water levels due to drought conditions at the end of WY2011. Salinities in the eastern and central areas of Florida Bay were high throughout the WY2012 wet season. Salinity in the mangrove zone of Highway Creek and Barnes Sound was above 50 practical salinity units (PSU), the highest levels since 1991. In addition, the 30 day moving average salinity at Taylor River remained above 30 PSU for a total of 55 days, exceeding the Minimum Flows and Levels criterion for Florida Bay. Heavy rains at the end of the wet season averted a violation.

WILDLIFE ECOLOGY

The 2012 wading bird nesting season was relatively unsuccessful and is the third consecutive nesting season of relatively poor breeding in South Florida. For most species, this year was characterized by late initiation of nesting, depressed nest counts, reduced clutch size, and poor fledging success. Poor nesting effort was likely most influenced by effects of preceding drought conditions from WY2011 on aquatic prey production, while fledging success was considerably reduced by rain-induced water-level reversal in late April and May. The Loxahatchee Impoundment Landscape Assessment (LILA) facility continues to be an effective "living laboratory" for evaluating fish, crayfish, wading bird, and hydrology interactions. This year, a LILA pilot study was initiated to assess the movement of fish across various Everglades depth features and habitats (deep alligator hole, slough, ridge) under differing hydrologic conditions. This study successfully tested the use of passive integrated transponder tags to monitor the diurnal movements of native fish across the depth features. Additionally, the prey base in the Florida Bay Transition Zone is described.

PLANT ECOLOGY

The two plant projects discussed in this chapter focus on hydrologic impacts and restoration goals. One study examines the plant understory development on the constructed tree islands in LILA. It was found that the developing woody canopy exerts a strong influence on understory vegetation composition and species richness. At the other end of the watershed in Florida Bay, submerged aquatic vegetation (SAV) and algal communities were monitored to provide an understanding of the effects of water management on and status of vital wetland and estuarine plant communities and habitat.

In Florida Bay, widgeon grass (*Ruppia maritima*) is largely limited to the region of greatest variability — the mangrove ecotone between the freshwater Everglades marshes and the saline bay. In this region, widgeon grass forms a critical habitat for marine and freshwater wildlife and thus is a focal species for Everglades restoration. In WY2012 a decrease in SAV cover was measured in the mangrove transition zone and in nearshore areas of Florida Bay. At sites farther into the bay and away from shore, SAV cover was relatively stable compared to last year. Seed germination rates were low and primarily restricted to salinities less than 25 PSU. However, experiments showed that germination was enhanced when seeds were previously exposed to higher salinity for a brief period. These results suggest that osmotic shifts from high to low salinity stratify widgeon grass seed coats promoting germination.

ECOSYSTEM

Three ecosystem-scale projects are reported in this chapter. First, an update on Active Marsh Improvement (AMI) — a project designed to provide a better understanding of the effect of physical removal of cattail using herbicides — is provided. AMI builds upon the results of the Cattail Habitat Improvement Project (CHIP), which assessed whether creating openings in dense cattail areas sufficiently alter trophic dynamics such that wildlife diversity and abundance increased and determined to what extent these created open areas function compare to the natural Everglades. As part of AMI, methods to restore the historical sawgrass ridge and open water slough structural patterning within nutrient-enriched cattail areas are being explored, as well as appropriate herbicide treatment rates to remove cattails while minimizing damage to other plants.

The second ecosystem-scale project, a study of tree island community structure in Everglades National Park, indicated that vegetation composition is greatly linked to a fluctuating hydrology; thus giving flexibility to the management of water levels in the Everglades. These results show that management thresholds are needed for extreme events (either high or low water levels) so that tree island resilience is enhanced.

Studies of Florida Bay water quality and ecohydrology showed that a previously undetected source of colored dissolved organic matter (CDOM) was identified in the northeast corner of Seven Palm Lake, which is related to freshwater flow. It seems likely this will increase with wet season flows and work its way through the chain of lakes to the bay. Monitoring of surface water nutrient concentrations and loads demonstrated the influence of Taylor Slough and the C-111 basin water management on upstream soil salinity and porewater nutrients, and on downstream salinity and nutrient distributions. Sediment core incubations showed that high nutrient concentrations and chlorophyll *a* in several ENP lakes may be more related to the lakes' long water residence time and possibly to groundwater or other nutrient sources.

LANDSCAPE

Two remote sensing projects and one landscape-scale study are described in this section. The mapping of tree islands in Shark River Slough using aerial photography from the 1950s to 2000s found a significant loss in the number and area of tree islands. In another study, researchers examined the potential for using WorldView 2 (WV2) satellite imagery to provide the basis for vegetation mapping of the EPA. Maps created using WV2 data preserved the shapes of landscape features at a high precision even when the minimum mapping unit was increased if the morphological aggregation algorithms rather than grid-based methods were used. Additionally, the ability to map at a high resolution then aggregate to lower resolutions provides a way to quantify the effects of heterogeneous communities on the spectral signatures of coarser resolution satellite data, such as that derived from Landsat imagery.

The DECOMP Physical Model (DPM) will examine the impacts of restoring flow between Water Conservation Areas 3A and 3B. To reproduce pre-drainage flow conditions, new structures are being built for the experiment, including 10 gated culverts on the L-67A levee, a 3,000 ft gap in the L67C levee, and three 1,000 ft canal backfill treatments in the adjacent canal. With a combined discharge capacity of 750 cubic feet per second, the culverts are expected to generate water velocities of 2–5 centimeters per second. This report focuses on the data collected in the DPM under the baseline, low-flow conditions. Sources of temporal and spatial variability are highlighted and a preliminary landscape sediment budget is presented as a means to synthesize the different data types. The measured variables reported on are: flow velocity and direction, water chemistry, and sediment transport and accumulation rates.

Table 6-1. Water Year 2012 (WY2012) (May 1, 2011–April 30, 2012) Everglades research findings in relation to operational mandates[1].

Project	Findings	Mandates[1]
Hydrology		
Hydrologic Patterns for WY2012	The amount of rain in the Everglades Protection Area (EPA) for WY2012 was substantially more than last year and similar to average historic conditions. WY2012 rainfall amounts were slightly above average for all the Water Conservation Areas (WCAs). However, in Everglades National Park (ENP), the rainfall was 1.4 inches (10.7%) less than the historical average, but still 1.4 inches (3.0%) more than last year. Salinities in the mangrove zone at Highway Creek and Barnes Sound were above 50 practical salinity units (PSU), the highest levels reported there since 1991. At Taylor River, the 30 day moving average (dma) salinity remained above 30 PSU for 55 days, an exceedance of the Minimum Flows and Levels (MFL) criterion for Florida Bay. A near-violation of the Florida Bay MFL was averted by heavy rains in the late dry season.	ROS MFL
Wildlife Ecology		
Wading Bird Nesting Patterns	Nesting effort and success was limited for most species with wood storks (*Mycteria americana*), tricolored herons (*Egretta tricolor*), and snowy egrets (*E. thula*) faring particularly poorly. Roseate spoonbills (*Platalea ajaja*) had a moderately successful year. All species initiated nesting relatively late in 2012, possibly due to reduced fish production following the 2011 drought. As a consequence, nestlings were relatively young when the rains arrived early in April, prompting widespread nest failure. This effect was particularly acute for the wood stork, which exhibited comprehensive nest failure in 2012.	ROS CERP MFL FEIM
Fish Habitat Preference Study	The feasibility of combining passive tagging and enclosure techniques in a pilot study conducted in the Loxahatchee Impoundment Landscape Assessment (LILA) to determine fish habitat selection and movement under varying hydrologic conditions was successfully tested.	CERP MFL ROS
Prey Base in the Florida Bay Transition Zone	Exotic species remained scarce across the region in WY2011 following a substantial cold-induced die-off in the winter of WY2010. Furthermore, the effects of a strong El Niño in WY2010 resulted in very high water levels and below average salinity, providing a hydrologic buffer against a dry year in 2011. These beneficial hydrologic conditions contributed to very high mean fish densities at most stations, especially in Shark and Taylor River Slough watersheds where most sites saw record numbers of fish in the dry season samples and had the highest mean fish densities for the respective periods of record.	CERP MFL ROS
Plant Ecology		
Community Succession on Constructed Tree Islands	In this study, understory species composition on LILA experimental tree islands significantly differed between 2009 and 2010. Results support the idea that the developing woody canopy exerts a strong influence on understory vegetation composition and species richness.	CERP EFA ROS
Florida Bay Submerged Aquatic Vegetation (SAV) Community	There was generally good spatial cover of SAV throughout the bay in WY2012, and no evidence of large-scale dieoff. In fresher areas, surveys of widgeon grass (*Ruppia maritima*) showed a generally low density seed bank, but several important "hot spots" of high concentrations of viable seeds that may enhance recruitment, particularly in the more nutrient-rich areas of the central bay.	CERP MFL ROS

119 **Table 6-1.** Continued.

Projects	Findings	Mandates[1]
Ecosystem Ecology		
Active Marsh Improvement	Preliminary vegetation observations indicate that the time of year herbicide treatment is applied has a significant impact on subsequent cattail reinvasion. In addition, recent aerial photographs of the cattail habitat improvement project suggest the sustainability of created openings is linked to local hydrologic conditions, with cattail reinvasion occurring at a slow rate and less expansively in areas with shorter hydroperiods and shallower depths.	LTP ROS
Changes in ENP Tree Island Community Structure	The vegetation composition on tree islands located within the northeastern Shark River region found a positive relationship between the normalized Brady-Curtis dissimilarity and habitat heterogeneity, suggesting that processes that enhance habitat heterogeneity along the environmental gradient have produced zones of high species turnover. Also, β-diversity was higher in 2011 than 2001, suggesting that resource heterogeneity on the tree islands has increased over the last 10 years, which could be due to both relatively dry conditions and interannual variability in water depth.	CERP MFL ROS
Florida Bay Water Quality and Ecohydrology	In most areas of Florida Bay and the transition zone, annual average concentrations of all of the water quality parameters measured have stabilized during the last three water years. High-resolution mapping shows a previously undetected source of colored dissolved organic matter (CDOM) in the northeast corner of Seven Palm Lake, which is related to freshwater flow. Taylor Slough and the C-111 basin can impact soil salinity patterns. Chlorophyll *a* levels in several ENP lakes may be related to the lakes' long water residence time.	CERP MFL ROS
Landscape		
Areal Losses and Gains in Tree Island Habitat in the ENP	Tree islands were mapped within Shark River Slough for each decade since the 1950s. Results of the mapping demonstrate that tree island habitat, as defined by the mapping criteria, has substantially declined in Shark River Slough and the immediately adjacent wet prairie habitats during the latter half of the twentieth century.	CERP EFA ROS MFL
Everglades Vegetation Classification Using WorldView 2 Satellite Data	The maps made from WorldView 2 satellite data preserved the shapes of landscape features at a high precision even when the minimum mapping unit was increased if the morphological aggregation algorithms rather than grid-based methods were used.	CERP EFA ROS MFL
Baseline Conditions for the DECOMP Physical Model	The DECOMP Physical Model (DPM) addresses uncertainties associated with the effects of sheetflow and canal backfilling. Data collected in the DPM under the baseline, low-flow conditions found a sediment accumulation per meter length of canal of approximately 17.0 kilograms per meter per year (kg/m/yr). This value is three-fold higher than the expected rate if it were assumed that all canal sediments are derived from marsh sediment transport (5.5 kg/m/yr).	CERP EFA ROS MFL

[1]**Mandates**

CERP	Comprehensive Everglades Restoration Plan
EFA	Everglades Forever Act, Section 373.4592, Florida Statute (F.S.)
FEIM	Florida Everglades Improvement and Management
LTP	Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area
MFL	Minimum Flows and Levels, Section 373.042, F.S., Chapter 40E-8, Florida Administrative Code
ROS	Regulation and Operational Schedules

120

HYDROLOGIC PATTERNS FOR WATER YEAR 2012

Fred Sklar and Amanda McDonald

The amount of rain in the Everglades Protection Area (EPA) for Water Year 2012 (WY2012) (May 1, 2011–April 30, 2012) was substantially more than last year and similar to average historic conditions. WY2012 rainfall amounts were slightly above average for all the Water Conservation Areas (WCAs) as shown in **Table 6-2**. However, in Everglades National Park (ENP or Park), the rainfall was 1.4 inches (10.7%) less than the historical average, but still 1.4 inches (3.0%) more than WY2011. In Water Conservation Areas 1 and 2 (WCA-1 and WCA-2), the rainfall was only 2.0 inches (3.9%) more than the historical average, but was 10.1 inches (23.1%) more than last year. Like WY2011, Water Conservation Area 3 (WCA-3) experienced the most dramatic deviations from the year before of any region. The rainfall in WCA-3 was 3.7 inches (7.2%) more than the historical average and was 14.2 inches (34.7%) more than WY2011.

Despite above average precipitation during WY2012, stages for WCA-1, WCA-3 and the ENP were, on average, 0.25 feet (ft) lower than WY2011 (a drought year) and similar to the historic averages (**Table 6-2**). Despite higher rainfall, water depth in WY2012 was lower in the previous year, which may be attributable to: (1) lag times associated with hydrologic responses to the very low stages in WY2011 (a buffering characteristic at the landscape scale), (2) WY2012 rainfall during high temperature months when evapotranspiration (ET) is high, and (3) erroneous conclusions based upon averages rather than the time series.

This is the first time in the 16-year history of reporting in the *South Florida Environmental Report* (SFER) that four water years are included in the discussion of the ecology of the Everglades. The purpose is to highlight the time-series patterns of stage associated with having two droughts in the last four years and to discuss the ecological implications of a drought-wet-drought-wet sequence on the restoration of wading birds. In review, the WY2009 drought was a fantastic year for many species of wading birds, WY2010 flooding was a terrible year for most wading birds, the WY2011 drought was not a good year, and WY2012 was good for some species, but bad for most.

Table 6-2. Average (calculated by subtracting elevation from stage), minimum, and maximum stage [feet National Geodetic Vertical Datum of 1929 (ft NGVD)] and total annual rainfall for WY2012 in comparison to historic stage and rainfall.[1]

	Rainfall (inches)		Stage (ft NGVD)						
			WY2012			Historic			Elevation
Area	WY2012	Historic	Mean	Minimum	Maximum	Mean	Minimum	Maximum	(ft NGVD)
Water Conservation Area 1	53.9	51.96	15.69	13.07	16.86	15.63	10.0	18.16	15.1
Water Conservation Area 2	53.9	51.96	12.23	10.22	13.85	12.52	9.33	15.64	11.2
Water Conservation Area 3	55.1	51.37	9.56	7.25	11.17	9.56	4.78	12.79	8.2
Everglades National Park	53.8	55.22	5.89	4.33	6.76	5.99	2.01	8.08	5.1

[1] See Chapter 2 of this volume for a more detailed description of rain, stage, inflows, outflows, and historic databases.

Figures 6-1 through **6-7** highlight the average stage changes in each of the WCAs for the last four years in relation to the recent historic averages, flooding tolerances for tree islands, drought tolerances for wetland peat, and recession rates and depths that support both nesting initiation and foraging success by wading birds. These indices were used by the South Florida Water Management District (SFWMD or District) to facilitate weekly operational discussions and decisions. Tree island flooding tolerances are considered exceeded when depths on the islands are greater than 1 ft for more than 120 days (Wu et al., 2002). Drought tolerances are considered exceeded when water levels are more than 1 ft below ground for more than 30 days, i.e., the criteria for Minimum Flows and Levels (MFLs) in the Everglades (SFWMD, 2006). **Figures 6-1** through **6-7** show the ground elevations in the WCAs as being essentially the same as the threshold for peat conservation.

The wading bird nesting period is divided into three categories (red, yellow, and green) based upon foraging observations in the Everglades (Gawlik, 2002). A red label indicates poor conditions due to recession rates that are too fast (greater than 0.6 ft per week) or too slow (less than 0.04 ft for more than two weeks). A red label is also given when the average depth change for the week is positive rather than negative. A yellow label indicates fair conditions due to poor foraging depths (i.e., depths greater than 1.5 ft), slow recession rate of 0.04 ft for a week, or rapid recessions between 0.17 ft and 0.6 ft per week. A green label represents good conditions and is assigned when water depths decrease between 0.05 ft and 0.16 ft per week and water depths are between 0.1 ft and 1.5 ft.

WATER CONSERVATION AREA 1

Following an exceptionally smooth and steady recession rate from November 2008 until May 2009 (**Figure 6-1**) — a recession rate that fostered record-breaking nesting and foraging for WY2009 — water levels rose about 1 ft over a two-month period. This is not an extreme rehydration rate, but just enough to bring optimum foraging conditions to an end. At this late stage in the nesting season, the invertivorous (feeding on invertebrates) white ibis (*Eudocimus albus*), the dominant species nesting in WCA-1, were able to weather the reversal by feeding in the Everglades Agricultural Area (EAA) and urban environments, and very large numbers of nestlings fledged successfully. Water depths in WCA-1 for the WY2011 dry season followed the same smooth and steady recession rates as WY2009, producing highly favorable foraging conditions. However, in WY2011 the dry season began at a lower stage than in WY2009, depths got much lower than the drought of WY2009, and low water depths continued into the WY2012 wet season (June 2012–July 2012). This intrusion of the WY2011 dry season into the WY2012 wet season created a large hydrologic deficit that was difficult to overcome. This was most apparent in WCA-3 (**Figure 6-5**) and Shark River Slough (**Figure 6-7**).

The water level changes in WCA-1 during the WY2012 wet season and part of the dry season were below average. Wading bird foraging and nesting were average to below average (Cook and Frederick, 2012) and dry season recession rates were good despite a couple of reversals. The WCA-1 regulation schedule tends to maintain deeper conditions than the rest of the Greater Everglades. As a result, relatively good nesting and foraging is common in this region during periods of droughts. For WY2012, hydrological conditions in support of wading bird foraging were considered good at the start of the season, yet relatively few birds nested or foraged here (Note: the severity of the WY2011 drought may have reduced the production of wading bird prey). Moreover, the region got too wet, too early in the nesting season, allowing the potentially "limited" prey resources to scatter across the marsh towards the end of the fledgling period. The 2009–2012 hydrographs (**Figure 6-1**) for WCA-1 suggest a long-term trend of above-average foraging and nesting. For the last four years, the hydrograph indicates mostly green arrows.

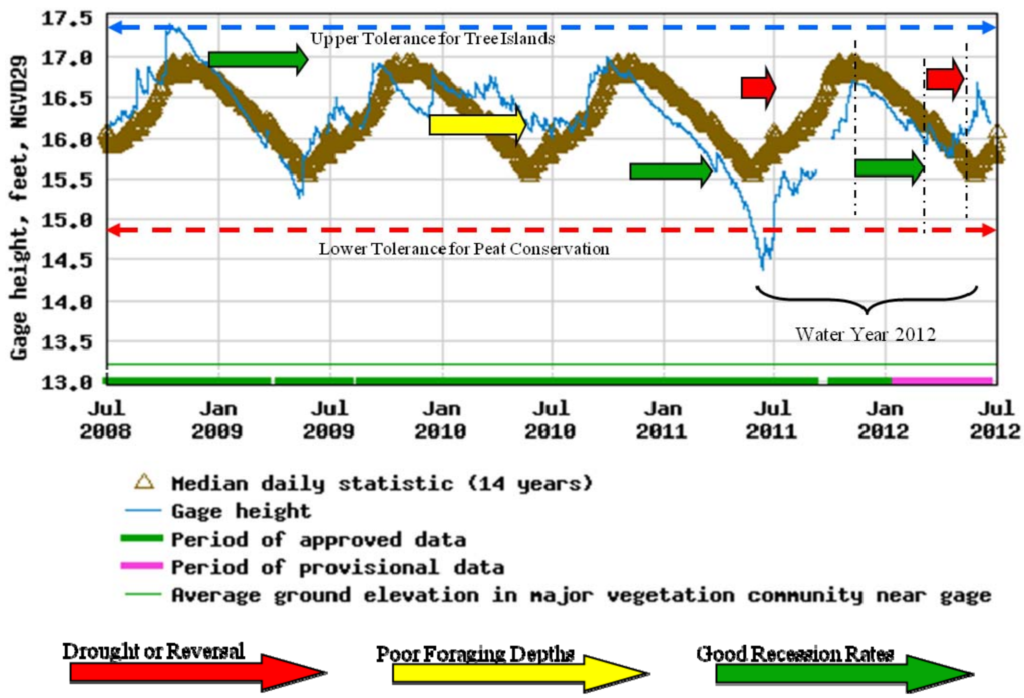


Figure 6-1. Hydrology in Water Conservation Area 1 (WCA-1) in relation to the 14-year median stage, as well as indices for tree island flooding, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 2A AND 2B

During the wet season, stage levels commonly exceed the upper flood tolerance for tree islands for one to two months in WCA-2A as it did in WY2009 (**Figure 6-2**) and the previous three years. Although one to two months will not cause long-lasting tree island damage (Wu et al., 2002), it is believed that it is good for tree islands to dry-out occasionally (Heisler et al., 2002). For the last three years, water levels during the wet season have been below the upper tolerances for tree islands (**Figure 6-2**), which is good for the remaining islands and possibly a period of rejuvenation for the "ghost" islands that remain. Future efforts to restore WCA-2A tree islands will require a closer examination (i.e., frequency analysis) to see if this kind of hydropattern can enhance the return of woody species to these marshes.

In WY2011, good recession rates were short lived in WCA-2A and were followed by a rapid and long-lived period of peat oxidation (**Figure 6-2**). During WY2012, water rehydration rates during the wet season and recession rates during the dry season were excellent for vegetation and sapling survival, and wading bird foraging, respectively (Note: The lack of tree islands in WCA-2A and 2B makes these regions unsuitable for nesting). As with the other regions in the EPA, the question remains: Were the WY2012 prey densities for wading birds below average and if they were, was this due to the previous drought, the very successful WY2011 dry season foraging, or both? The 2009–2012 hydrographs (**Figure 6-2**) suggest a long-term trend of above average foraging. For the last four years, the hydrograph indicated equal distributions of green and red arrows.

WCA-2B tends to be utilized by wading birds during droughts because it often stays deeper for longer periods than the rest of the EPA. This was true in WY2009 when dry season water levels went below ground in WCA-2A and northern WCA-3A, and the wading birds moved to WCA-2B. It was not true in WY2011 when dry season water levels went almost 2.5 ft below ground for an extended period (**Figure 6-3**). It was ecologically problematic for water levels to increase by some 4 ft over a few months as this region rehydrated in WY2012. This rapid water level rise killed young tree seedlings established during the previous drought. Nevertheless, this region consistently gets a poor foraging depth designation (yellow arrows). The 2009–2012 hydrographs (**Figure 6-3**) suggest a long-term trend of poor foraging and nesting.

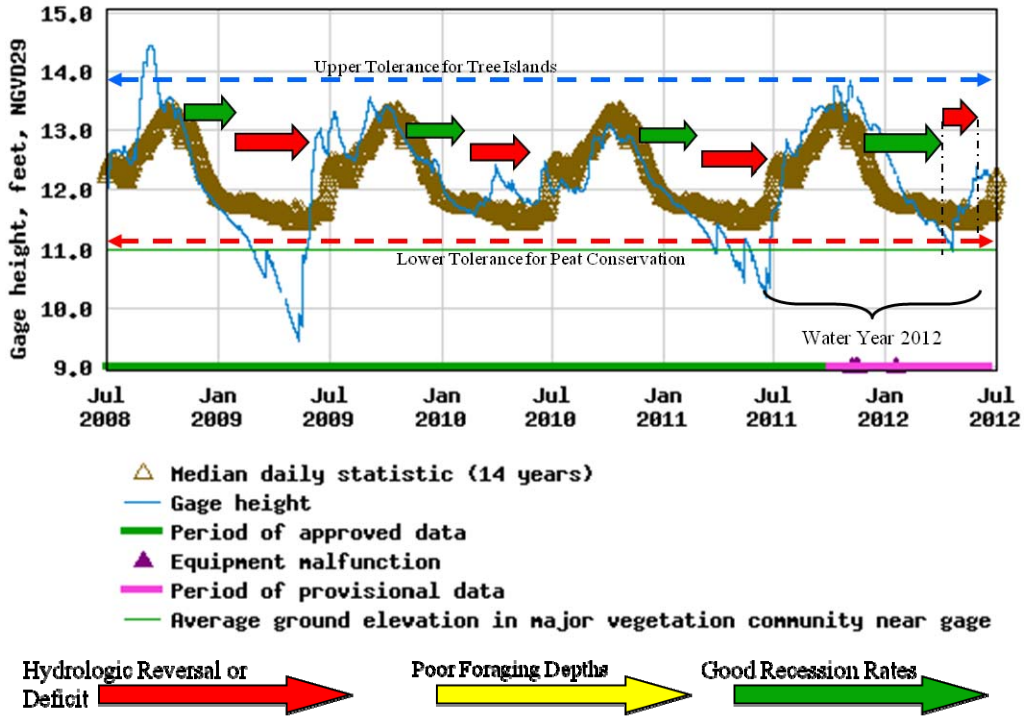


Figure 6–2. Hydrology in Water Conservation Area 2A (WCA-2A) in relation to the recent 14-year median stage, with indices for tree islands, peat conservation, and wading bird foraging.

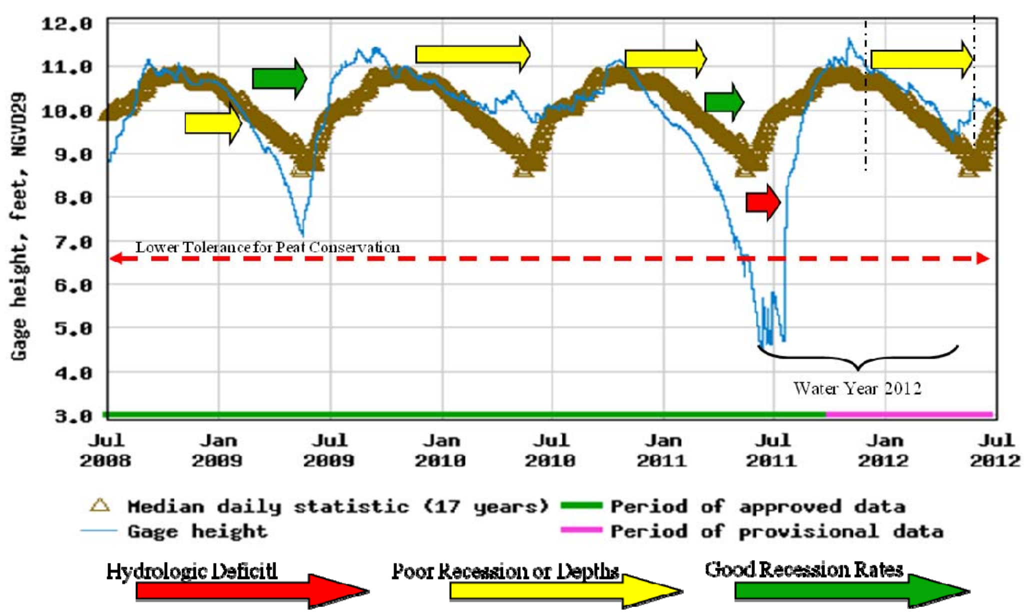


Figure 6–3. Hydrology in Water Conservation Area 2B (WCA-2B) (gauge 99) in relation to the recent 17-year median, with indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3A

In the northeastern region of WCA-3A (gauge 63), WY2012 began with an extensive and intensive dry period (**Figure 6-4**). Water levels were significantly below average from May until December. A few marsh fires occurred in the northern and central areas; why they were not peat burns and why they were contained is unknown. Recession rates were excellent starting in December (good for wading birds) and optimum depths started to appear around January 2012. Water levels during the dry season stayed high and average to large numbers of foraging birds were in this section of WCA-3A from February until May. In May, surface water rapidly increased, causing prey to disperse, foraging to decline, and nests to be abandoned (see *Wildlife Ecology* section). Of particular interest was the return of roseate spoonbills (*Platalea ajaja*) that nested successfully at various colonies in WCA-3A in 2011. This species typically nests in the coastal habitats of Florida Bay. The 2009–2012 hydrographs (**Figure 6-4**) for this section of WCA-3A suggest a long-term trend of average foraging and nesting. For the last four years, the amount of time when this location was "red" was substantially less than when the system was yellow or green, which may indicate that this region of the Everglades in consistently valuable for foraging.

Within the central area of WCA-3A (gauge 64) the hydrologic pattern was conducive for wading bird foraging (**Figure 6-5**). However, moving out of the WY2011 drought took some time and water levels stayed below average until December when depth exceeded tree island tolerances for a few weeks. Like most regions, WY2012 was probably good for foraging in the central Everglades, but poor for prey rejuvenation due to the good dry season recession rates. Average to small flocks of wading birds were observed following the receding drydown fronts in central WCA-3A during WY2012. The 2009–2012 hydrographs for this section of WCA-3A suggest a long-term trend of above average foraging and nesting.

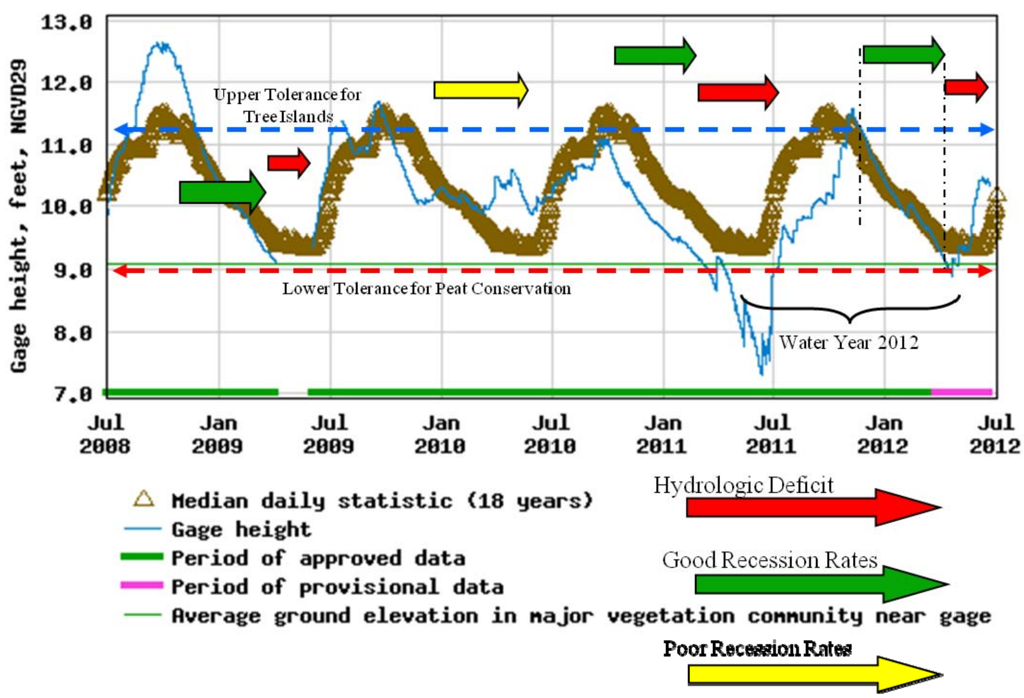


Figure 6-4. Hydrology in northeast Water Conservation Area 3A (WCA-3A) (gauge 63) in relation to the recent 18-year median with indices for tree islands, peat conservation, and wading bird foraging.

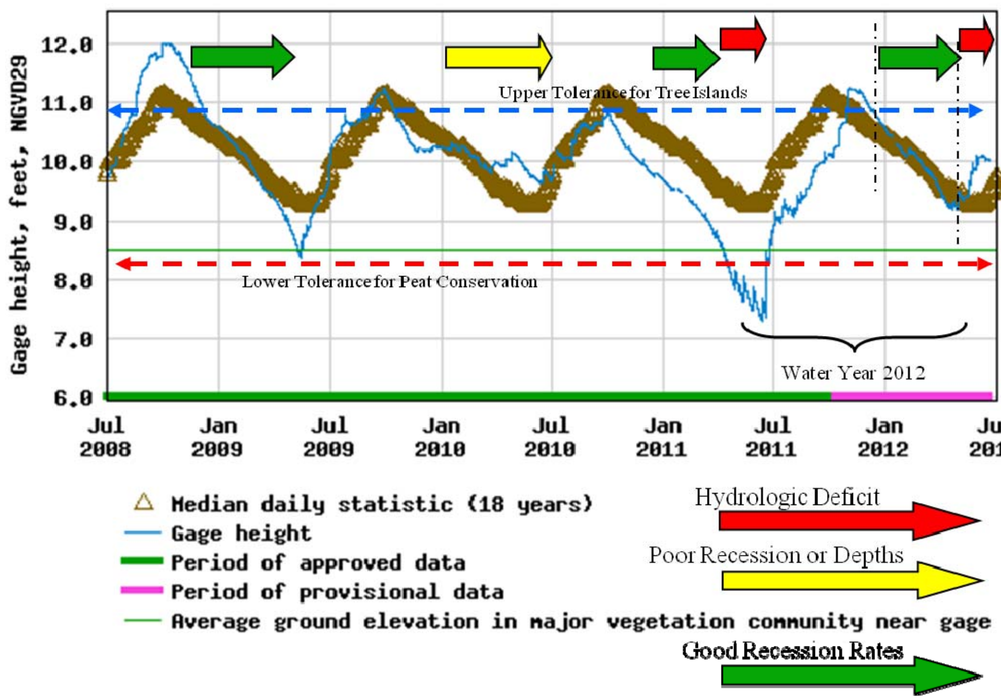


Figure 6-5 Hydrology in central WCA-3A (gauge 64) in relation to the recent 18-year median with indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3B

During the WY2011 drought, water levels in WCA-3B fell at an almost steady perfect rate of 0.10 ft per week throughout the dry season. January and February foraging by wading birds was excellent. Then, as with everywhere else in the EPA, there was an abrupt water level decline in April and May 2012, followed by an intensive dry season with a water depth of 2.0 ft below ground. Recovery from the extensive drydown took time and the WY2012 wet season stages were far below average. Unlike most of the EPA, WCA-3B held on to its dry season water. Water depths and recession rates were good for foraging by wading birds, but it appears that foraging was very limited. There are three probable explanations for the limited foraging: (1) the lack of sloughs in WCA-3B and thus a lack of foraging habitat, (2) the extensive WY2011 dry down and thus a lack of prey, or (3) a combination of a lack of foraging habitat and prey. As the prey density data are processed over the next year or so, it will be valuable to see if low foraging intensity was due to the WY2011 drought and a lack of prey or if the low foraging intensity was due to a lack of good foraging habitat. The dry season in WCA-3B ended early in May, thus making the foraging season very limited. The 2009–2012 hydrographs for WCA-3B suggest a long-term trend of average foraging and nesting. For the last four years, the hydrograph (**Figure 6-6**) indicated equal distributions of green, yellow, and red arrows.

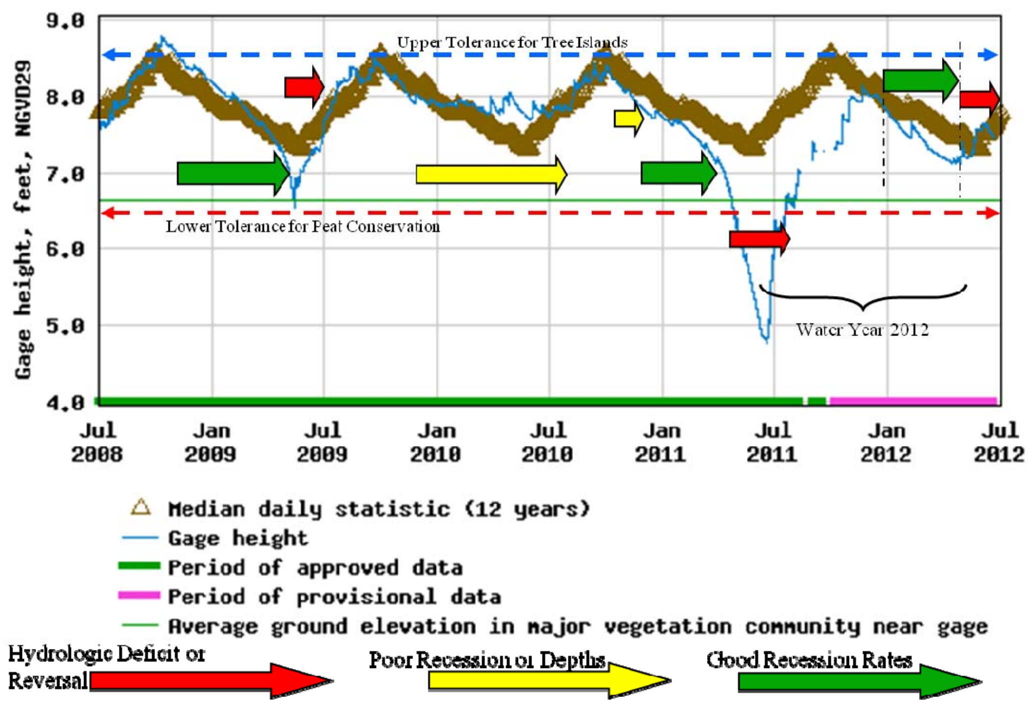


Figure 6-6. Hydrology in the central Water Conservation Area 3B (WCA-3B) (gauge 71) in relation to the recent 12-year median and indices for tree islands, peat conservation, and wading bird foraging.

NORTHEAST SHARK RIVER SLOUGH

In WY2011, the dry season had good recession rates for a few months in northeast Shark River Slough (**Figure 6-7**). However, water levels decreased quickly and stayed dry for four months and as a result did not support wading bird foraging or nesting. Like the rest of the EPA, recovery from the extensive drydown took time and the wet season stages were much below average. Water levels returned to normal around December and recession rates were excellent for the entire nesting season. However, although not all the WY2012 data has been processed, foraging success was below average during the WY2012 dry season and it came to an early end due to the early onset of the WY2013 wet season. The 2009–2012 hydrographs for this section of the Park suggest a long-term trend of sub-optimum foraging and nesting. For the last four years, the hydrograph (**Figure 6-7**) indicated mostly red and yellow arrows.

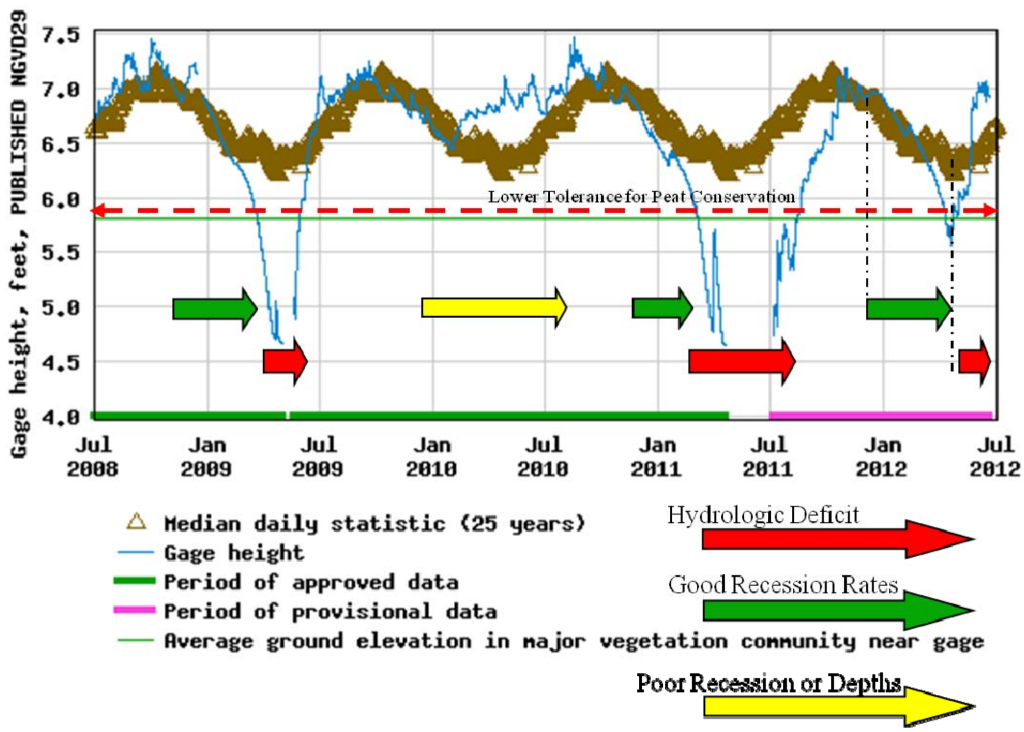


Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 25-year median with indices for tree islands, peat conservation, and wading bird foraging.

FLORIDA BAY

To provide a continuous record of the salinity profile of Florida Bay, upstream sites in the watershed, and major creek discharge sites, the District and other agencies have maintained a long-term monitoring network throughout the southern Everglades and the bay. This information supports District operations, is important in developing and monitoring Comprehensive Everglades Restoration Plan (CERP) performance measures, assessing effectiveness of MFLs, and supporting calibration and verification of hydrologic models.

Methods

Salinity and flow in Florida Bay are monitored hourly at instrumented platforms. Several monitoring platforms in the bay are located in pairs: one near the shoreline, more influenced by creek discharges, and one further offshore in open water (**Figure 6-8**). Grab samples were taken at additional fixed monitoring sites monthly until October 2011 and every other month since then.

Results

At the beginning of WY2012, high salinities and low water levels prevailed in Florida Bay and the bordering mangrove transition zone due to drought conditions at the end of WY2011. Heavy rains toward the end of the wet season returned salinities to near normal levels by November in WY2012. The WY2012 wet season experienced a slow start, and rainfall for the Florida Bay watershed was below the historic average, leading to increased salinity downstream in the mangrove ecotone and Florida Bay. The monthly radar-estimated rainfall for the Florida Bay Basin did not peak until August, two months later than typical. By this time, the rain deficit was approximately 7 inches below the average for WY1997–WY2010. High rainfall at the end of the dry season reduced the water year deficit to approximately 5 inches.

Creek flow into Florida Bay followed the trend of rainfall. Flows from the five creeks discharging to eastern and central Florida Bay were below average for the first five months of the water year (**Figure 6-9**). The cumulative annual discharge of approximately 179,052 acre-feet (ac-ft) [approximately 22,086 hectare-meters (ha-m)] was 30 percent lower than the WY1997–WY2010 average of 257,920 ac-ft (31,814 ha-m).

Salinities in the eastern and central areas of Florida Bay were elevated throughout the WY2012 wet season (**Figure 6-10**). In particular, sites at Highway Creek and Barnes Sound in the mangrove zone experienced salinities above 50 practical salinity units (PSU), the highest levels reported since 1991. Salinities returned to normal conditions at the end of the wet season aided by higher than average October rainfall.

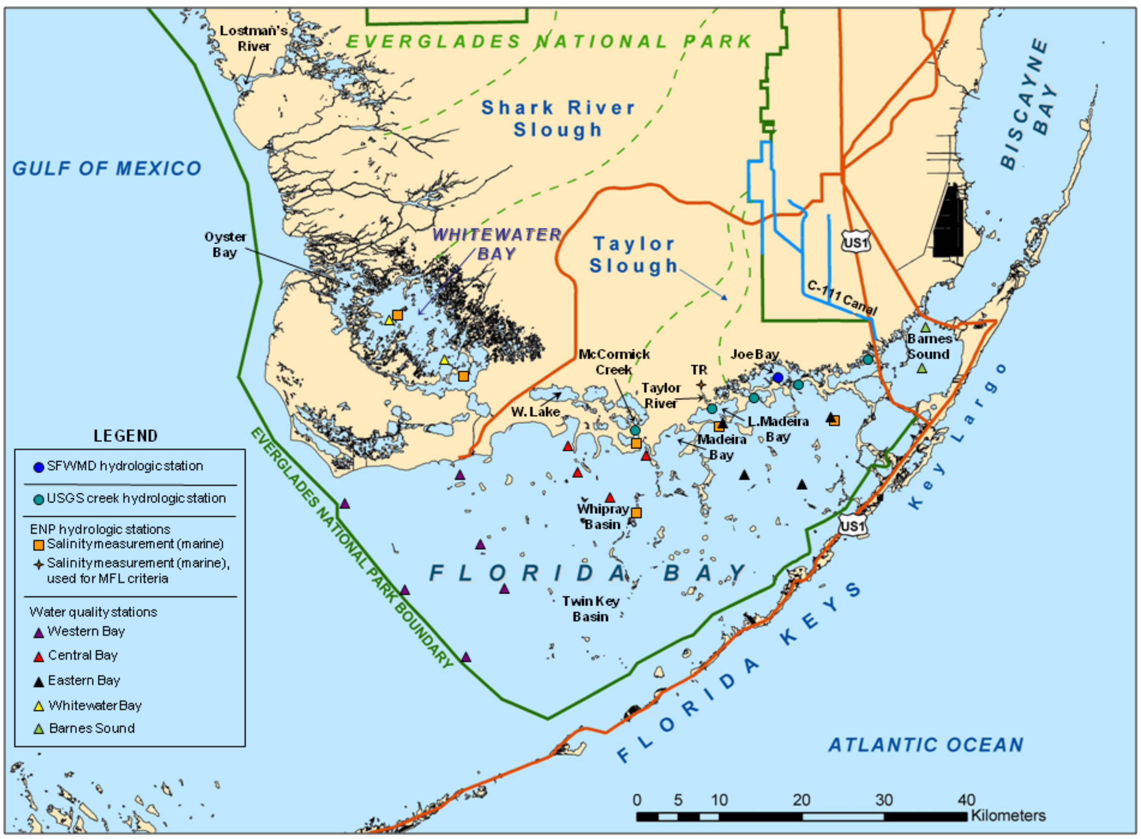


Figure 6-8. Salinity sampling points within Florida Bay and southern Everglades, showing areas influenced by water management operations from Whitewater Bay in the west to Barnes Sound in the east. Environmental parameters are monitored by the South Florida Water Management District (SFWMD), United States Geological Survey (USGS), and Everglades National Park (ENP).

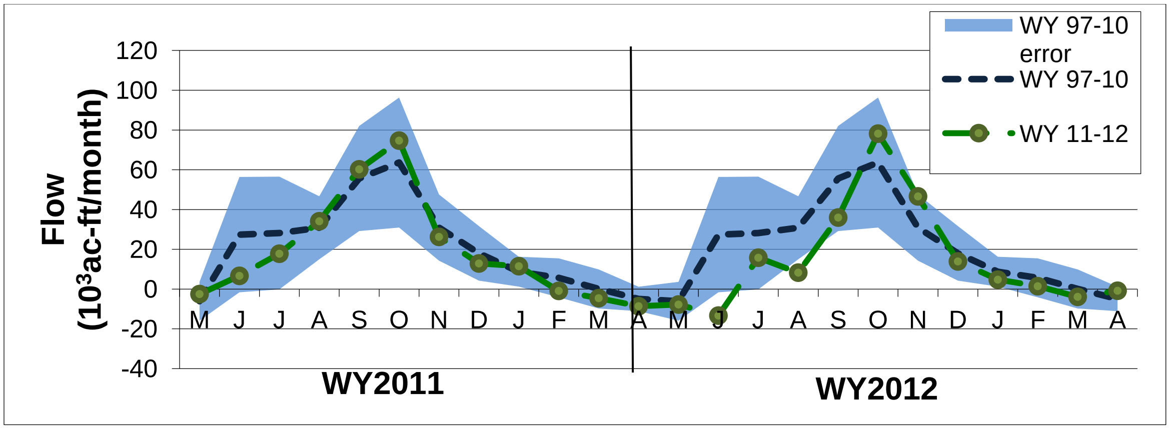


Figure 6-9. Monthly cumulative discharge to Florida Bay through five creeks in WY2011 and WY2012 (WY11-12 in the legend), compared to monthly discharge mean (WY97-10) and standard deviation envelope (WY97-10 error) for WY1997–WY2010. Data after September 2010 are provisional, supplied courtesy of the USGS.

Relevance to Water Management

When the 30 day moving average (dma) salinity measured at the upstream Taylor River platform rises above 30 PSU, it is considered an exceedance of the Florida Bay MFL criterion. The combined impact of reduced direct rainfall over Florida Bay and reduced inflows from the watershed, especially during the beginning of the wet season, led to high salinities and an exceedance of the Florida Bay MFL rule on May 30, 2011. The 30 dma salinity at Taylor River remained above the MFL threshold salinity for a total of 55 days.

The MFL rule allows for two such exceedances in consecutive calendar years only once during a 10-year period. A second instance of exceedance in two consecutive calendar years constitutes a violation of the MFL rule. Salinity in the mangrove ecotone during the dry season began rising approximately a month earlier than normal, increasing at a rate of about 2–3 PSU per week by the end of March in WY2012. Because consecutive-year exceedances occurred in WY2009 and WY2010, an exceedance that began in WY2012 and carried over into WY2013 (May 1, 2012) would have been a violation. However, heavy rainfall in April of WY2012 caused a rapid decline in salinity, averting an exceedance and violation. The 30 dma salinity peaked at 27.5 PSU on April 24, 2012, and was 26.6 PSU on April 30 (the end of WY2012).

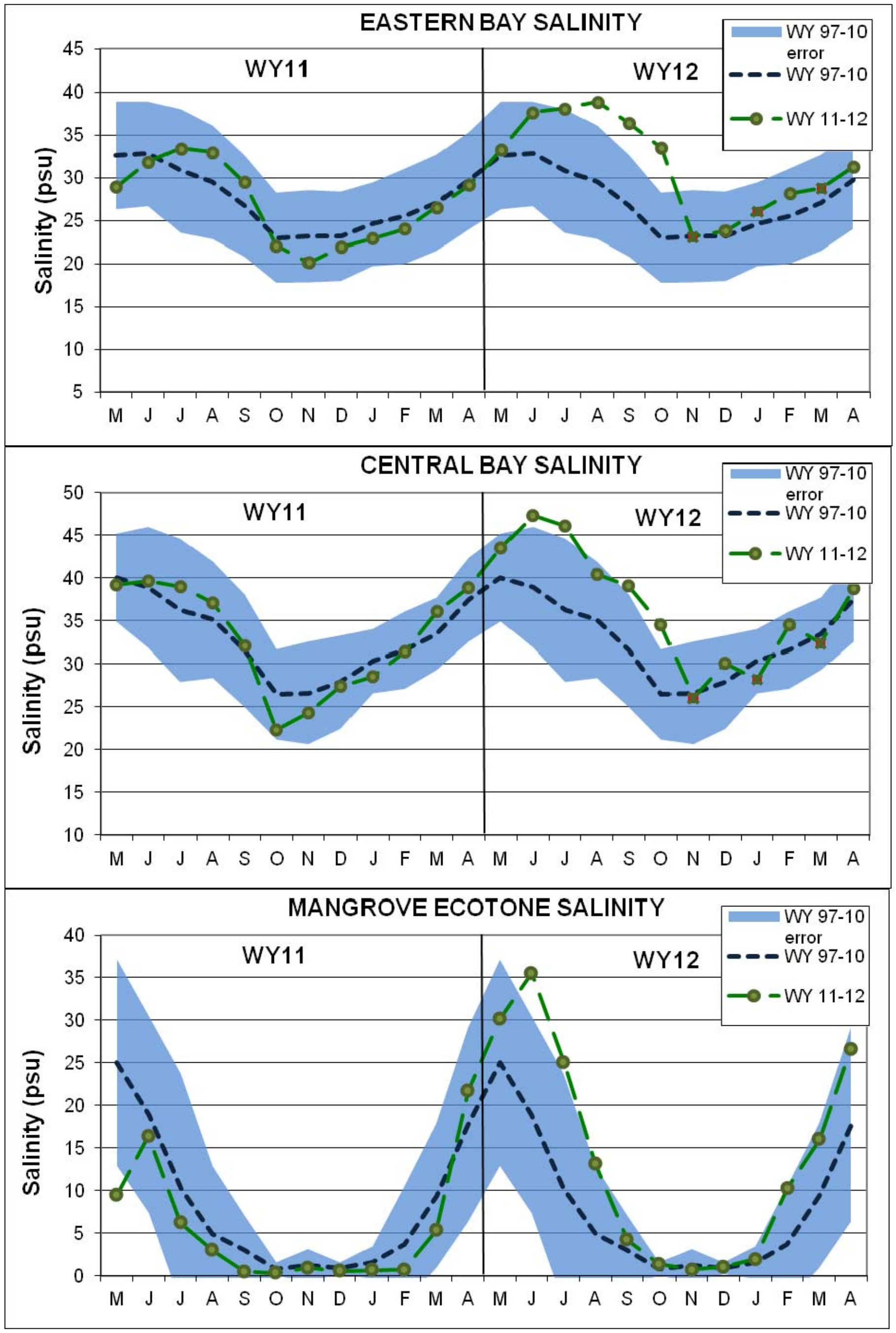


Figure 6-10. Mean monthly salinity values in eastern Florida Bay (top), central Florida Bay (middle), and the mangrove ecotone at the ENP-Taylor River platform (bottom) in WY2011–WY2012 (WY 11-12 in the legend), compared to monthly means (WY 97-10) and standard deviation (WY 97-10 error) for WY1997–WY2010. The eastern and central bay salinity values are averaged between continuous monitoring platforms and monthly grab samples coincident with water quality sampling. Beginning in October 2011, the water quality sampling was reduced to every other month and the months missing the grab samples in the average are denoted by the red squares on the WY11-12 line (November, January, and March of WY2012 for the Eastern Bay and Central Bay).

WILDLIFE ECOLOGY

Robin Bennett, Eric Cline, Mark Cook, Jennifer Rehage[1], Melissa Anderson[1], Ross Boucek[1], Amy Narducci[1] and Amartya Saha[1]

Large populations of colonially nesting wading birds (order Ciconiiformes; egrets, ibises, herons, spoonbills, and storks) were a common and defining feature of the pre-drainage Everglades. Long-term records of their nesting stretch back to the early part of the last century, and some clear reproductive responses to anthropogenic alterations have been established, such as:

- A marked decline in the nesting populations of several species, particularly tactile foraging species
- A movement of colonies from the over-drained estuarine region to the more ponded interior marshes
- A marked decrease in the frequency of exceptionally large aggregations of nesting white ibises
- Delayed nest initiations of wood storks by a few months (from November/December to February/March), resulting in reduced nestling survival

These responses appear to be consistent with mechanisms that involve foraging and specifically the role that hydrology plays on the production and vulnerability to predation of aquatic prey animals.

The District currently focuses its wildlife research toward gaining a better understanding of the links among hydrology, aquatic prey availability, and wading bird foraging and reproduction. This research has improved both the District's capacity to effectively manage the system and ability to predict future restoration scenarios. This utility of the research stems not only from an improved knowledge of how key ecological drivers affect wading bird reproduction, but also from the recasting of these data into practical spatially explicit tools to predict foraging and nesting responses to physical and biological processes in real time and space. This section summarizes wading bird nesting effort and success during the WY2012 breeding season, describes a project to assess the movement of fish across various Everglades depth features or habitats under differing hydrologic conditions in the Loxahatchee Impoundment Landscape Assessment (LILA) area, and reports on Florida Bay fish production.

WADING BIRD MONITORING

Wading birds are excellent indicators of wetland ecosystem health and have a central role in CERP. Nesting figures for CERP performance measures are restricted to colonies in the Greater Everglades Region, i.e., the WCAs and the ENP, for the following species:

- Great egret (*Casmerodius albus*)
- Snowy egret (*Egretta thula*)
- Tricolored heron (*Egretta tricolor*)
- White ibis (*Eudocimus albus*)
- Wood stork (*Mycteria americana*)

The timing of breeding, number of nests, and location of nesting colonies within the Everglades are used as CERP targets to evaluate the progress of the Everglades restoration effort.

[1] Florida International University, Miami, FL

In addition to CERP, wading birds are of special interest to the public and play a prominent role in adaptive protocols, MFLs, and day-to-day operations of the District.

Recovery of pre-impoundment (1930–1940) wading bird nesting patterns is evaluated using the following parameters (Ogden et al., 1997; Frederick et al., 2009):

- Increase and maintain the total number of pairs of nesting birds in mainland colonies to a minimum of 4,000 pairs of great egrets, 10,000–20,000 combined pairs of snowy egrets and tricolored herons, 10,000–25,000 pairs of white ibises, and 1,500–2,500 pairs of wood storks.
- Shift timing of nesting in mainland colonies to more closely match pre-impoundment conditions. Specific recovery objectives would be for wood storks to initiate nesting no later than January in most years and for ibis, egrets, and herons to initiate nesting in February–March in most years.
- Return of major wood stork, great egret, ibis/small egrets, and heron nesting colonies from the Everglades to the coastal areas and the freshwater ecotone of the mangrove estuary of Florida Bay and the Gulf of Mexico.
- Reestablish historical distribution of wood stork nesting colonies in the Big Cypress Basin and in the region of mainland mangrove forests downstream from the Shark River Slough and Taylor Slough basins. Increase the proportion of birds that nest in the southern ridge and slough marsh-mangrove ecotone to greater than 50 percent of the total for the entire EPA.
- For wood storks, restore productivity for all colonies combined to greater than 1.5 chicks per nest.
- Return to an interval between exceptional white ibis nesting events, defined as greater than the 70th percentile of annual nest numbers for the period of record.

Summary of Nesting Year 2012

The information reported in this section represents a compilation of data collected by various institutions, including Florida Atlantic University (FAU), University of Florida (UF), Everglades National Park (ENP), Audubon Society, and others. The population estimates reported here are simply the totals of the independent surveys and are not adjusted according to the appropriate significant figures because the precision of each independent survey estimate is unknown. The counts include all wading bird species (except cattle egret, *Bubulcus ibis*) nesting throughout South Florida during January–July 2012. For further details on independent sampling methods see Cook and Kobza (2010).

An estimated 26,395 wading bird nests were initiated throughout South Florida during the 2012 nesting season. This estimate is comparable to those of 2011 (26,452) and 2010 (21,885) and is the third consecutive year of relatively poor nesting effort in the region (**Figure 6-11**). The 2012 estimate represents a 39 percent decline relative to the decadal average, and a 66 percent decline relative to the 77,505 nests for 2009, which was the best nesting year on record in South Florida since the 1940s. All species of wading birds suffered reduced nest numbers relative to the past 10 years, but the extent of the decrease varied among species. Great egrets exhibited a relatively minor decline (9%) in nest numbers relative to their 10 year average, while wood storks (44%), white ibises (39%), and snowy egrets (56%) suffered greater declines. Of particular note was the limited nesting by little blue herons (*Egretta caerulea*) and tricolored herons (only 89 and 412 nests, respectively), which continues a steep and steady decline in their nesting activity for the past eight years. By contrast, roseate spoonbill nesting effort (348 nests) in Florida Bay improved relative to recent years (404% greater than in 2011) although it remains lower than the decadal average and the historical period. The dramatic increase in spoonbill nesting activity observed in WCA-3A during 2011 was evident again in 2012. This year there were 176 spoonbill nests in the WCAs, a 260 percent increase on the average for the past 10 years.

Most wading bird nesting in South Florida occurs in the Greater Everglades. In 2012 an estimated 24,191 nests (92% of all South Florida nests) were initiated either in the WCAs or the ENP. This estimate is 40 percent lower than the decadal average and 66 percent lower than in 2009 when a record high of 73,096 nests was recorded in the Everglades. Most other parts of South Florida experienced similar declines in nest numbers during 2012. Of particular note is the reduction in wood stork nests at Corkscrew Swamp Sanctuary. Wood storks have historically nested annually in Corkscrew in relatively large numbers, yet the 2012 nesting season was the fifth year of the past six when storks failed to breed there. Such an unprecedented decline in nesting activity may reflect a serious reduction in the extent or quality of wood stork foraging habitat in southwest Florida during recent years.

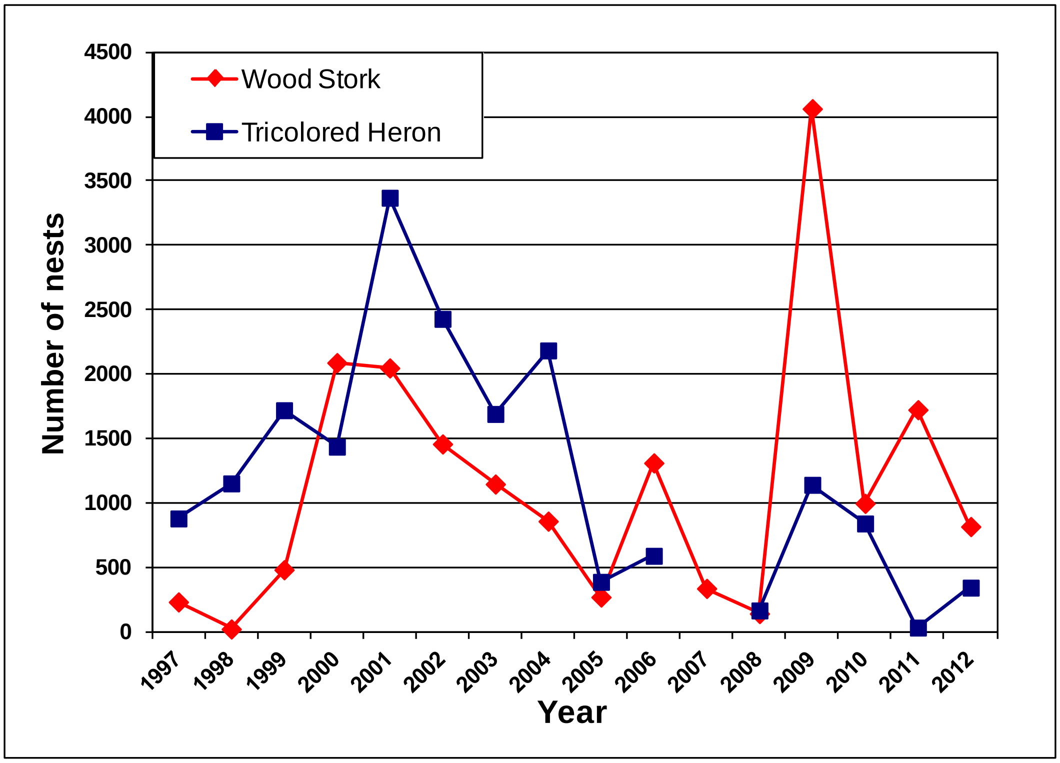
Spatial coverage of systemwide nest surveys was expanded to include Lake Okeechobee and the Kissimmee River floodplain in 2005, and Estero Bay Aquatic Preserve in 2008. The marshes around Lake Okeechobee supported 3,079 wading bird nests in 2012, which represents a decline in nesting effort relative to recent years (5,636 and 6,737 nests in 2011 and 2010) but is a marked improvement on 2008 when only 39 nests were recorded around the lake. On the recently restored section of the Kissimmee River floodplain wading birds are not yet nesting in significant numbers, and this year only 148 nests were recorded. However, nesting effort is not expected to improve until hydrologic conditions are restored in 2015. For comparative purposes with prior years' nest counts, these three regions are not included in the above systemwide total.

The ENP historically supported the largest number of nests in the Greater Everglades, but in recent decades most nesting has occurred inland in the WCAs. CERP's goal is to restore the hydrologic conditions that will reestablish prey production and availability across the landscape that, in turn, will support the return of large successful wading bird colonies to the traditional estuarine rookeries downstream of Shark River Slough. In 2012, the ENP supported a relatively large proportion of nests (40%), while WCA-3 and WCA-1 supported 51 percent and 9 percent, respectively. This spatial distribution of nests contrasts with the general pattern over the past decade when nesting was concentrated in WCA-1 and WCA-3A, while the ENP was relatively unattractive for nesting (an average of 16 percent of nests over the past decade). Nonetheless, the ENP has become more attractive to nesting birds in recent years, with the proportion of nests increasing to 20 percent and 21 percent in 2006 and 2009, and then jumping to over 40 percent in 2010. However, 2012's increase remains below the 50 percent CERP target and may be due to declines in nesting conditions in the WCAs rather than a marked improvement in habitat conditions along the marsh-mangrove ecotone.

Of note in 2012 was the late start to nesting for most species. Wood storks, which in recent decades have typically initiated nesting in January–February, did not start nesting until early to mid-March. Late starting dates were also noted for great egrets and, to a lesser extent, white ibises. Moreover, nest success was generally depressed for most species in 2012 relative to previous years. This was certainly the case in the WCAs, where overall nest success (the probability of fledging at least one young) was low for all species studied (great egrets, white ibis, tricolored herons, and snowy egrets). In the ENP, nest success varied considerably by species. Wood storks fared particularly poorly and it is thought that all 820 nests failed or were abandoned. By contrast, great egrets, snowy egrets, and white ibises were relatively successful based on anecdotal observations. Another region that experienced poor nesting success was Lake Okeechobee where most colonies experienced complete or extensive nest failure. The exception to this general pattern was roseate spoonbill nesting in Florida Bay where many colonies fledged on average more than one chick per nest.

Wading bird breeding patterns in South Florida are driven largely by hydrology through its influence on prey production and prey vulnerability to predation (Frederick et al., 2009). The 2012 breeding season was preceded by drought conditions in the WY2011 dry season followed by a relatively dry WY2012 wet season. Such conditions are generally unsuitable for small fish production (Trexler et al., 2005), but possibly promote crayfish production via predator release or nutrient pulse mechanisms (Dorn et al., 2011). Preliminary reports from the annual monitoring of prey production and concentration events in the Everglades suggest that WY2012 experienced reduced fish production but elevated crayfish production relative to recent years (N. Dorn, D. Gawlik, J. Trexler, pers. communication). A reduction in fish production would certainly account for the observed reduced nesting effort, late dates of nest initiation, small clutch sizes (P. Frederick, pers. communication), and reduced nest success experienced by piscivorous species such as the wood stork and great egret, but it is unclear why the crayfish-specializing white ibis suffered similar, although less extreme, breeding responses. With regard to prey vulnerability, recession rates and water depths were generally conducive to wading bird foraging from January through mid-April in WY2012 but several heavy rain events in late April and May promoted large-scale water-level reversals, dispersing concentrated prey. This led to high levels of nest failure and abandonment in many colonies in the Everglades.

Two of the four species groups met the numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force (**Table 6-4**). Two other targets for Everglades restoration are an increase in the number of nesting wading birds in the coastal Everglades and a shift in the timing of wood stork nesting to earlier in the breeding season (Ogden, 1994). The 2012 nesting year did not show an improvement in the timing of wood stork nesting or a sufficient shift of colony locations to the coast.



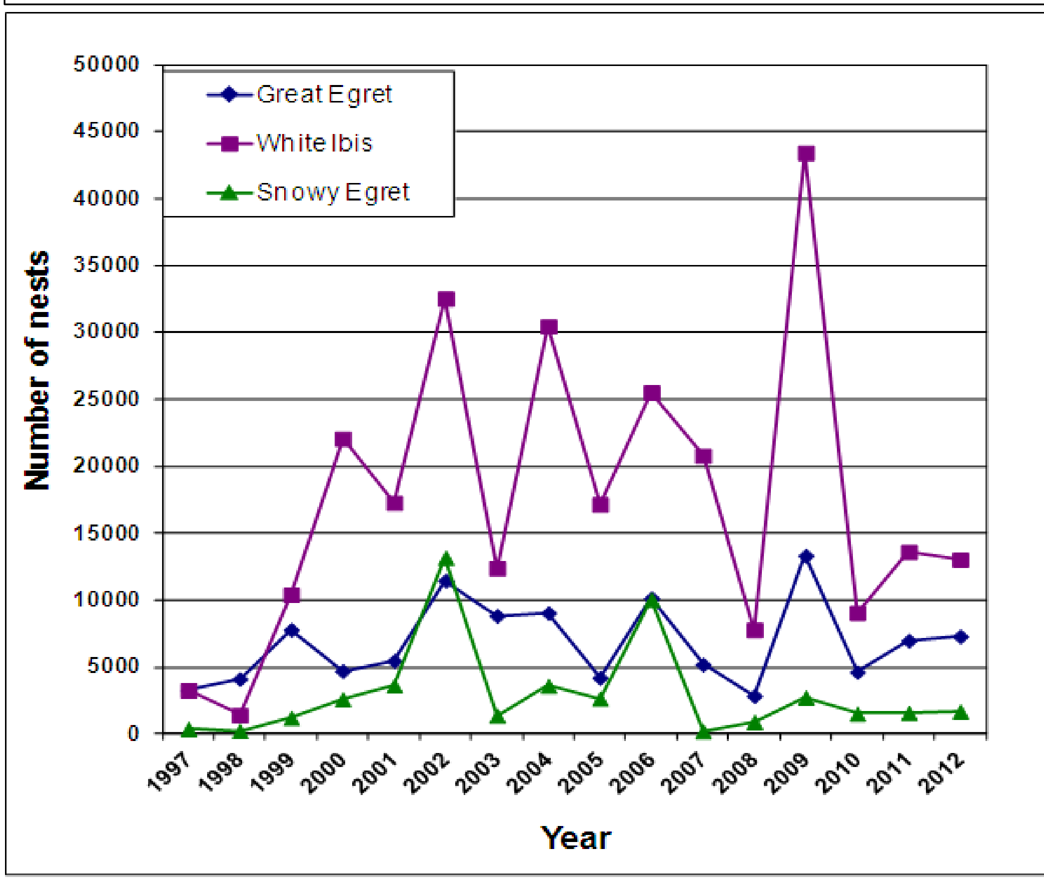


Figure 6-11. Historical wading bird nesting numbers in the Everglades for individual species since 1997.

Table 6-4. Wading bird nests in the WCAs and the ENP compared to CERP targets and historical ranges. Targets are based on known numbers of nests for each species during the pre-impoundment period (1930–1940) (Summarized by Ogden, 1994).

Species	2002-2004	2003-2005	2004-2006	2005-2007	2006-2008	2007-2009	2008-2010	2009-2011	2010-2012	Target
Great egret	9,656	7,829	8,296	6,600	5,869	6,956	6,774	8,303	6,296	4,000
Snowy egret/ Tricolored heron	8,079	4,085	6,410	4,400*	3,778	1,723	2,442	2,622	1,004	10,000-20,000
White ibis	24,947	20,993	24,926	21,133	17,541	23,953	20,081	22,020	11,889	10,000-25,000
Wood stork	1,191	742	800	633	552	1,468	1,736	2,263	1,182	1,500-2,500

EXAMINING FISH HABITAT CHOICE AND FINE-SCALE MOVEMENT

Understanding fish habitat selection and movement will help answer research questions about both aquatic ecology and prey availability for birds. However, obtaining animal movement data of sufficient resolution in time and space remains a major challenge, especially in open, lentic habitats like wetlands. This project tests the feasibility of combining passive tagging with enclosure techniques to gain this high resolution data in a pilot study.

Methods

In a pilot 7 m x 7 m enclosure at LILA, researchers tracked the movement and habitat use of passive integrated transponder (PIT)-tagged centrarchids [two warmouth (*Lepomis gulosus*), one bluegill (*L. macrochirus*), and two spotted sunfish (*L. punctatus*)] over 14 days (**Figure 6-12**). Within the enclosure, three flat-bed antennas encircled key Everglades marsh habitats of varying water depth: shallow ridge, mid-water slough, and deep alligator hole. For the replicate study (**Figure 6-13**), six enclosures (12 m x 4 m) were constructed and outfitted with vertical antennas connected to readers (Oregon RFID) powered by deep cycle batteries recharged by solar panels. Redear sunfish (*L. microlophus*), largemouth bass (*Micropterus salmoides*) and warmouth have been released into these enclosures and this study is in progress.

Results

The pilot setup retained fish for over 30 days and continuously tracked the movements and habitat selection of the five fish tested for 14 days. Fish used all three habitats with marked species-specific variation in diel movement patterns across habitats (**Figure 6-14**). Similar data is being obtained from the six-enclosure study that is in progress (**Figure 6-15**).

Conclusion

These findings suggest that the combination of PIT tags, multiple antennas, and enclosures can be a productive way of gaining detailed and continuous data on the movement and habitat use of multispecies assemblages of small-bodied fishes.

Relevance to Water Management

This technology provides wildlife scientists and water managers with a better understanding of the dynamics among fish behavior, hydrology, and ultimately wading bird foraging success. Provided this fine scale information on fish movement, water managers can better predict how hydrology will influence the availability of fish as prey items for wading bird populations.

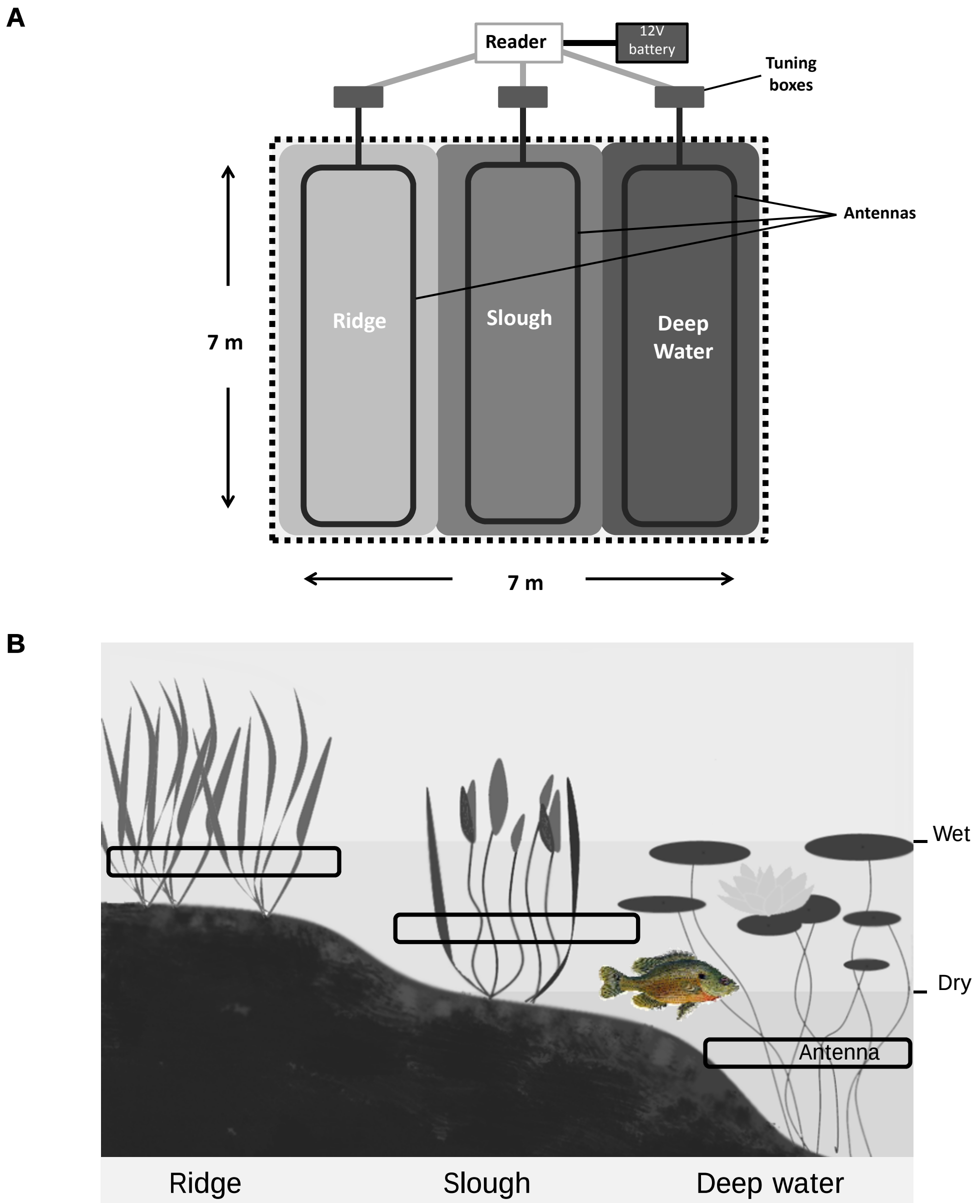


Figure 6-12. (A) Top and (B) lateral views of the three habitats contained in the 7 m x 7 m enclosure, showing vegetation types, seasonal water depth, and flat top antenna layout surrounding shallow ridge, mid-water slough, and deep-water alligator hole habitats.

Figure 6-13. Enclosures built at LILA. Each enclosure includes ridge (right), slough (center) and deep water (left, with water lilies), the three habitats associated with increasing water depth, typical of Everglades wetland savanna.

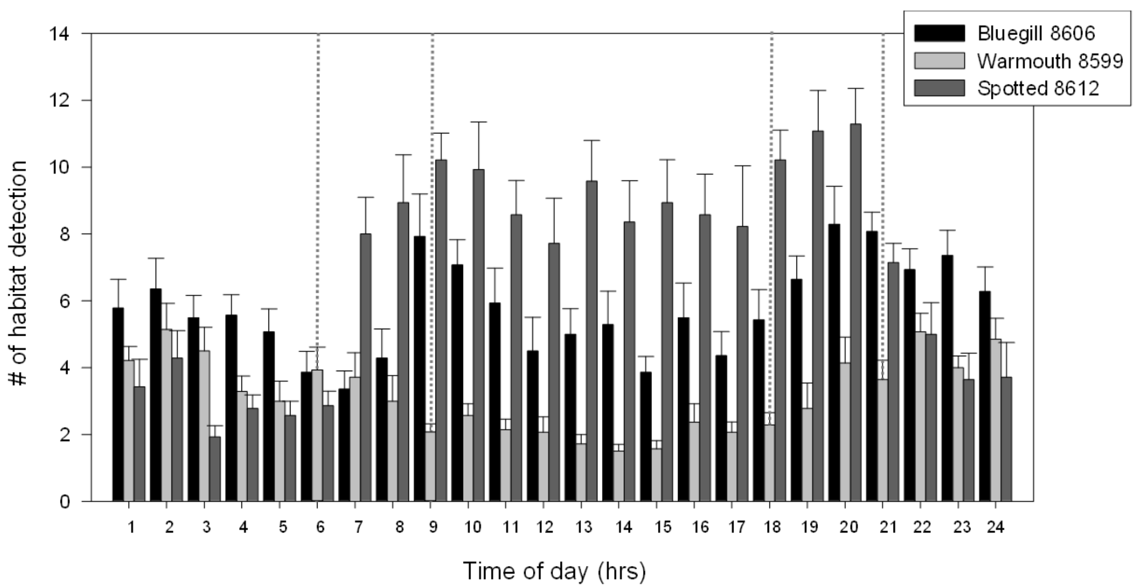


Figure 6-14. Diel pattern in activity shown as the mean number of habitats visited per hour for three of the five focal fish: bluegill (*Lepomis macrochirus*, tag# 8606), warmouth (*L. gulosus*, tag# 8599), and spotted sunfish (*L. punctatus*, tag# 8612) across the 14 days of data collection. Dotted lines separate day, crepuscular (twilight), and night periods.

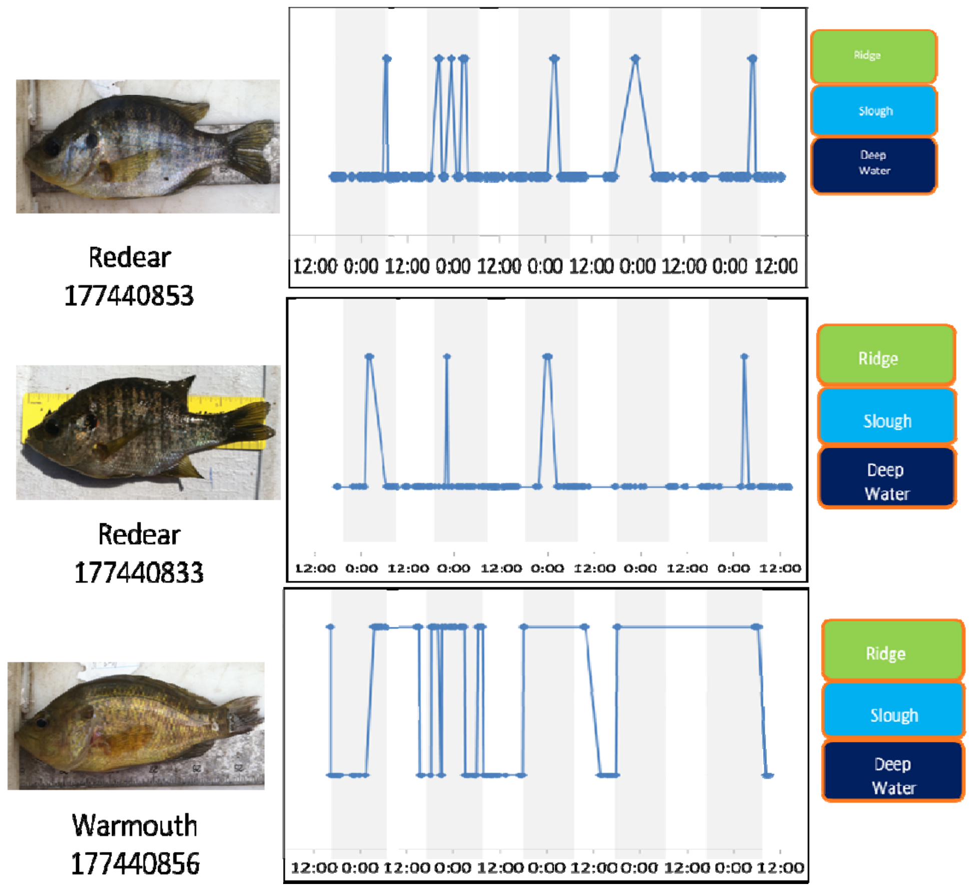


Figure 6-15. Tracking graphs of two redear sunfish (*Lepomis microlophus*) and one warmouth in enclosure 1 over five days in January 2012. One antenna was in the ridge while the other antenna was in the deep water. Both redear sunfish show forays into the shallow ridge only around midnight.

PREY BASE OF THE FLORIDA BAY SALINITY TRANSITION ZONE

Audubon of Florida's Tavernier Science Center maintains an extensive network of stations across the mangrove ecotone in wading bird foraging areas in the southern ENP (**Figure 6-16**). At these sites, hydrologic data are collected continuously (salinity and water level), submerged aquatic vegetation (SAV) surveys are conducted every other month, and prey-base fish are sampled eight times per year. The period of record for some stations extends from WY1991 to present, while others were initiated in the last decade. SAV and small prey-base fish are good ecological indicators because they serve as important links in the transition zone food web and, with quick growth and generation times, they are able to demonstrate a response to hydrologic and habitat conditions in a timeframe appropriate for water management. The Audubon monitoring network is thus well poised to reveal effects from changing operations through restoration (e.g., C-111 Spreader Canal Western Project) or other water management initiatives [e.g., Combined Operational Plan (COP), Florida Bay MFL rule].

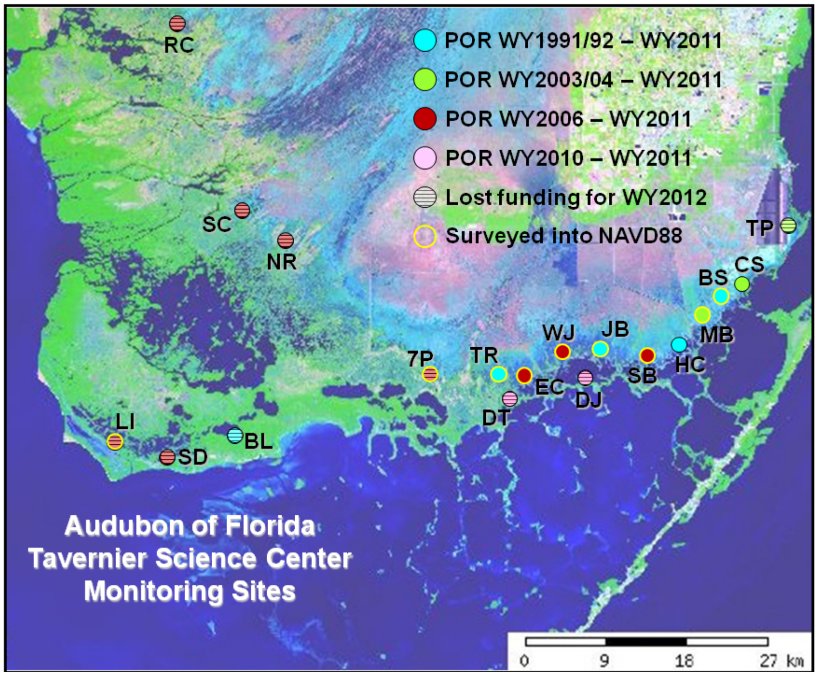


Figure 6-16. Audubon of Florida's monitoring stations, depicting changes to the network in WY2012 and surveys performed to adjust relative water level data to North American Vertical Datum of 1988 (NAVD88) stage (POR = period of record).

Methods

Details on the methods used to sample mangrove fish communities can be found in Lorenz et al. (1997). Audubon's sampling measures the number of fish in relation to the size of the wetland (fish abundance) and the concentration of fish into smaller pockets as the size of the wetland fluctuates due to the rising and lowering of water levels (fish availability). The first is calculated using a weighted stratified mean (Snedecor and Cochran, 1968) where each collection is weighted by the percent of potential flooded sub-habitat (creek or flats) that is actually inundated at the time of sample collection, thus correcting for the concentration effect of fluctuating water levels. Data are reported in terms of density (number of fish per square meter) and biomass [grams (wet weight) per square meter]. The second metric is relevant to how a predator perceives the availability of these prey species. Prey availability is estimated by determining which sub-habitat (creek or flats) has the highest overall number of fish per square meter of trap sampled, and is reported as available biomass (grams per square meter). Additional details can be found in Lorenz (1999) and Lorenz and Serafy (2006).

The Audubon's monitoring network underwent significant changes in WY2012. As part of the systemwide Restoration Coordination and Verification (RECOVER) monitoring optimization effort in summer 2011, 10 sites will no longer be monitored (**Figure 6-16**). In addition, elevation surveys have been completed for nine of Audubon's long-term hydrologic gauges to make them relative to the North American Vertical Datum of 1988 (NAVD88). This will improve water depth estimates for the coastal region and better describe conditions impacting wading bird species. Water level data for these stations should be able to be incorporated into the South Florida Water Depth Assessment Tool (SFWDAT) that updates water surface maps for the Greater Everglades and C-111 basins each day. The SFWMD is continuing to support the 7P hydrologic gauge (**Figure 6-16**) (though fish and SAV monitoring have been discontinued) because the surrounding area is both critical for the C-111 Spreader Canal Western Project and is poorly covered by other gauges.

Results and Discussion

The latest prey fish data available were from WY2011, with unvalidated results described from quarterly reports provided by Audubon staff to the SFWMD. Results from fish samples in WY2011 demonstrated the lag of effects from environmental conditions in the southern Everglades. Exotic species remained scarce across the region in WY2011 following a substantial cold-induced die-off in the winter of WY2010 (Frezza et al., 2011). Furthermore, very high water levels and below average salinity due to a strong El Niño in WY2010 provided the southern Everglades with a hydrologic buffer for what was otherwise a dry year in WY2011 (Frezza et al., 2012, Sklar et al. 2012). These hydrologic conditions contributed to very high mean fish densities at most stations, especially in the Shark River Slough and Taylor River Slough watersheds where most sites saw record numbers of fish in the dry season and had the highest mean fish densities for the respective periods of record (Frezza et al., 2012) (**left graphs in each panel, Figure 6-17**). The sites that did not follow these trends were largely in the Cape Sable region (LI, DS, BL), an area disconnected from managed inflows, or in close proximity to U.S. 1 (SB, HC, MB, BS). Frezza et al. (2012) documented shifting hydrologic conditions from the East Cape and Homestead Canals that are allowing salinity intrusion on Cape Sable, and from the reconnection of water bodies adjacent to U.S. 1 in northeast Florida Bay and southern Biscayne Bay.

The results for fish biomass in WY2011 were considerably different from the trends in fish density (**middle graphs in each panel, Figure 6-17**). Depth-adjusted mean prey biomass was significantly different from past years' collections only at a few sites. This was because the increased density of fish came mostly in the way of small native species such as rainwater killifish (*Lucania parva*) and mosquitofish (*Gambusia affinis*) that might otherwise be eaten by the larger exotic species (e.g., cichlids) mostly absent from the WY2011 samples. In terms of food available for wading birds and other large piscivores, the non-depth-adjusted available biomass data (**right graphs in each panel, Figure 6-17**) were very high in WY2011 compared to previous years due to both high buildup during the wet season (and previous wet WY2010) and a strong and steady concentration of these prey in the subsequent dry season when water levels dropped very low. As with fish density, available fish biomass in WY2011 was highest compared to previous years, particularly at sites in the Taylor Slough and Shark River Slough watersheds, and less so for sites near Cape Sable and adjacent to U.S. 1. These results demonstrate the importance of using both depth- and non-depth-adjusted values to summarize conditions for the prey base.

Quarterly status reports from Audubon reported that the late start to the WY2012 wet season (in the summer of 2011) allowed salinity to climb quite high in the mangrove transition zone, changing the prey communities to become more dominated by mesohaline and polyhaline species (Audubon, 2011). The reports also describe a resurgence of exotic fish species at all sites, in part due to a mild 2012 winter (Audubon, 2012). Anecdotal results suggest these factors may contribute to below average fish densities, and combined with rain-induced water level reversals during the winter of 2012, to low concentration of wading bird prey at Audubon's sites for WY2012 (Lorenz, 1999; Audubon, 2012).

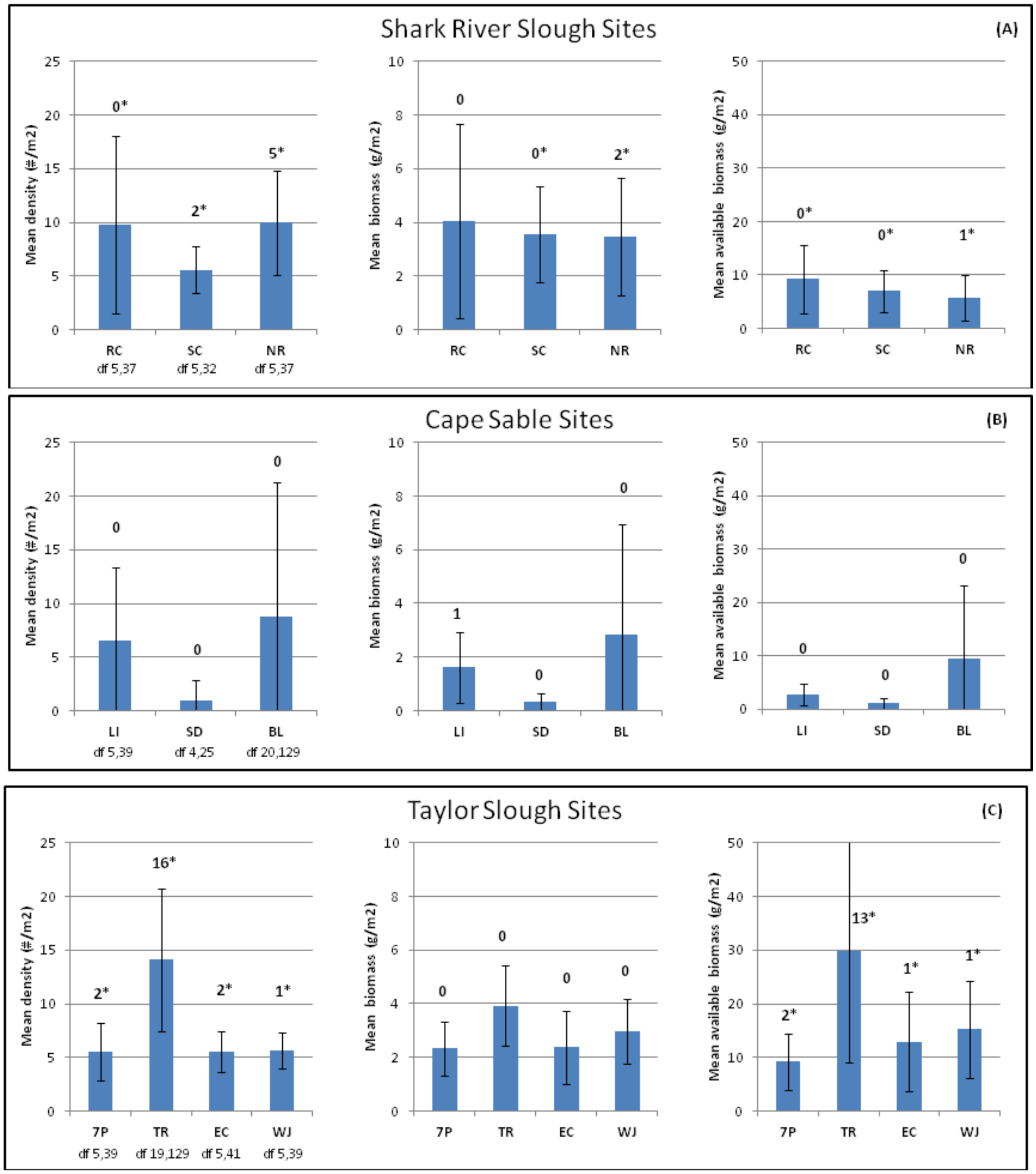


Figure 6-17. Comparison of depth-adjusted prey density and biomass, and non-depth adjusted available prey biomass for Audubon sites in five basins for WY2011. Data shown are means for each parameter, with error bars of ±1 standard deviation (calculated over the eight samples collected in WY2011). Numbers above each bar represent number of water years within each site's POR (see **Figure 6-16** for details) that were significantly different from WY2011 data, using a one-way Analysis of Variance (ANOVA) (on natural-log transformed data) and a Dunnett's multiple comparison test ($p < 0.05$, df as indicated for each site). An asterisk next to this number denotes that WY2011 saw the highest mean value for the POR. Data for sites DT and DJ are not presented because they had less than two full years of sampling and funding support ended in early WY2012.

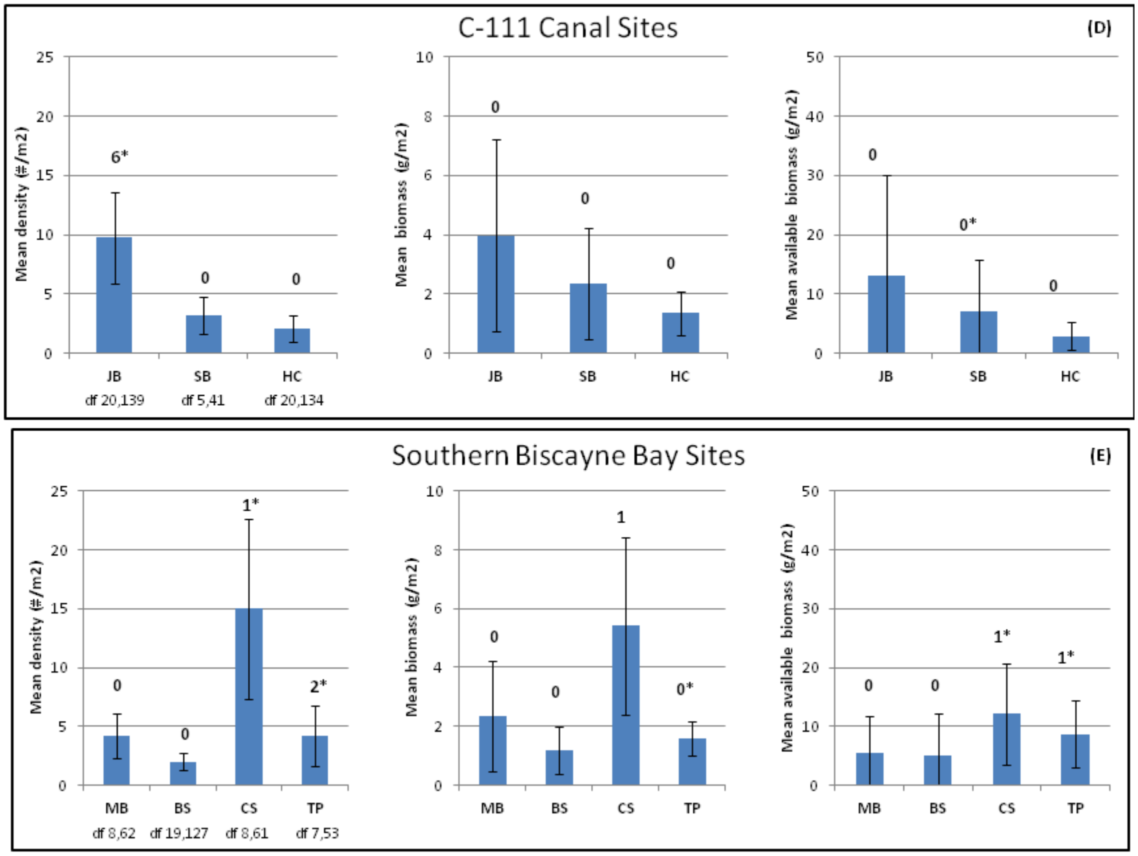


Figure 6-17. Continued.

Relevance to Water Management

In areas most affected by water management, prey fish communities in WY2011 showed significantly higher densities due to a very wet and cold WY2010, and significantly higher prey availability as a result of low water depths and uninterrupted recession in WY2011. These record prey concentration events in the southern Everglades did not translate into increased nesting effort by wading birds as seen by the number of roseate spoonbill nests in Florida Bay being lower than they had been in over 50 years (Frezza et al. 2012).

Changing hydrologic conditions described by Frezza et al. (2012) along Cape Sable and adjacent to U.S. 1 may obscure future trend analyses for these areas. Conditions are expected to improve for Cape Sable due to a large backfilling effort of the East Cape and Homestead Canals sponsored by the ENP, while conditions at sites near U.S. 1 should be monitored closely as this region is downstream from both the C-111 Spreader Canal Western Project and the C-111 South Dade Modified Water Deliveries Project.

PLANT ECOLOGY

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Plant studies form an important basis for evaluating restoration success. This section evaluates understory vegetation community development on constructed tree islands in LILA and presents a description of SAV and macroalgae in Florida Bay.

UNDERSTORY COMMUNITY SUCCESSION ON CONSTRUCTED TREE ISLANDS

This study was undertaken to explain how understory assemblages are organized along hydrology and light gradients in an early stage of succession within the LILA experimental tree islands. The objective is to determine if understory plant species in developing forests arrange themselves in response to variations in the availability of light resources when a hydrologic gradient exists that may impose drought stress at one end and flooding stress at the other.

Methods

In 2009, 192 permanent 1 m x 1 m plots were sampled for understory species composition on LILA tree islands. The understory included all herbaceous species and individuals of woody species less than 1 m in height. Plants within each plot were identified to species, and cover of each species was estimated using a modified Braun-Blanquet scale (1 = 0–1%, 2 = 1–4%; 3 = 4–16%; 4 = 16–33%; 5 = 33–66%; 6 = > 66%). In each plot, a photograph was taken with a digital camera and a hemispherical lens placed 1 m above the ground at the center of the plot used to assess canopy cover (Jonckheere et al., 2004) (**Figure 6-18**).

Figure 6-18. An example of the hemispherical photos taken of two plots to document canopy cover.

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Results and Discussion

Species Composition

Understory vegetation in a developing forest is strongly influenced by a complex set of physical site characteristics, and by environmental variables that are modified by the developing forest canopy. At the LILA site, stand age and substrate types determine observed variation among islands in understory vegetation, while the hydrologic gradient is the strongest determinant of community differentiation within an island. The light regime associated with the developing forest canopy further partitions the available habitat and determines species occurrence and abundance, especially on the drier portions of the islands.

In general, understory species composition on the tree islands significantly differed according to an Analysis of Similarity (ANOSIM; 1,000 permutations, $R = 0.012$, p-value = 0.006) of data collected in 2009 and 2010. While understory vegetation change in one year was significant in both 2006 and 2007 plantation cohorts (ANOSIM; p-value = 0.001 and 0.004, respectively), the shift in species composition was probably influenced by the changes in overstory cover. In both cohorts, canopy cover was higher in 2010 than in 2009, and such an increase in canopy cover was positively correlated ($r = 0.39$, $p < 0.001$) with elevation. Surprisingly, at the lowest elevations (mean water table at or above the tree island surface), canopy cover decreased in the majority of plots between 2009 and 2010. Effects of changes in canopy cover on the understory species composition varied along the hydrology gradient and also differed between two plantation cohorts. Especially on the islands planted in 2006, understory vegetation change patterns differed between low and high elevations. Vegetation composition in the high elevation plots shifted towards assemblages adapted to high canopy cover, whereas the opposite trend was observed at low elevations, possibly due to a decrease in canopy cover in many plots.

Species Richness and Distribution Pattern

In the understory of the developing forest at LILA, the number of plant species (gamma diversity) in 2010 was 88 compared to 91 in 2009. There were 20 species present in 2009 that were not recorded one year later and 17 species were recorded for the first time in 2010. Species richness (alpha-diversity, i.e., number of species per plot) in 2010 (5.8 ± 1.98) was significantly lower according to an Analysis of Variance (ANOVA: $F_{1,382} = 30.1$, $p < 0.001$) than in 2009 (7.0 ± 2.26). Since species richness is negatively related [Generalized Linear Model (GLZ); Deviance = 137, Wald Statistic 10.5, $p = 0.001$] to canopy cover, the lower richness in 2010 than in 2009 is attributed to an increase in canopy cover in one year.

In the developing forests at LILA, the distribution pattern of major species along the hydrology or light gradient did not differ much between 2009 and 2010. In 2009, of nine species with distribution affected by the interaction of water depth and canopy openness, three were flood-intolerant species [broomsedge bluestem (*Andropogon virginicus*), smallspike false nettle (*Boehmeria cylindrical*), and dog fennel (*Eupatorium capillifolium*)] whose abundance peaked in dry areas with moderate to deep shade. They were sometimes present in wet sites, but only at low abundance and only in locations where light availability was high. In contrast, flood-tolerant species did not show a consistent pattern. Some species that were abundant in relatively wet areas [e.g., beaked panicgrass (*Panicum anceps*) and maidencane (*P. hemitomon*)] decreased in cover with increasing light while others [e.g., Kissimmee grass (*Paspalum geminatum*) and bulltongue arrowhead (*Sagittaria lancifolia*)] were abundant in open areas but their cover decreased with decreasing light.

In 2010, only broomsedge bluestem showed a significant interaction effect of hydrology and canopy openness. Its mean cover, which was significantly lower in 2010 (10.9%) than in 2009 (16.4%), peaked in relatively open plots. Its abundance decreased with an increase in canopy cover, which was expected, as the species is known to be shade intolerant and drought tolerant, occupying mostly dry and open areas in the various stages of forest development (Bazzaz, 1968).

As in other successional studies, these results support the idea that the developing woody canopy exerts a strong influence on understory vegetation composition and species richness. Since many opportunistic species are ephemerally present in the early stage of forest development, species composition has changed somewhat, even in one year. This suggests that the understory composition will perhaps become much more organized over time, with changes in canopy structure and light availability responding to the management-induced hydrologic regime.

Relevance to Water Management

The restoration of a hydrology that promotes healthy tree islands and tree island rehabilitation is a cornerstone of the greater restoration effort. Linking hydrologic conditions, canopy openness, and the development of an understory on the tree islands at LILA gives water managers a way to better predict the trajectory of overall tree island health from changes in hydrology and perhaps what water conditions would be necessary for restoring currently impaired tree islands.

FLORIDA BAY BENTHIC VEGETATION COMMUNITY

Benthic vegetation, composed of seagrass and benthic macroalgae, provides habitat structure in Florida Bay and in creeks, ponds, and marshy areas of the mangrove transition zone. Monitoring and research of benthic vegetation is critical to gaining an understanding of the effects of water management and restoration on wetland and estuarine ecosystems. Results from these efforts are being applied to a review and potential revision of the Florida Bay MFL rule, which is currently based on the salinity tolerance of widgeon grass (*Ruppia maritima*), to assess the effects of the C-111 Spreader Canal Western Project and provide ecosystem status updates for RECOVER.

Methods

Benthic vegetation is monitored regionally in select locations using a randomized design where several 0.25 m^2 quadrats are assessed for benthic vegetation using indices of percent cover. Three separate monitoring programs cover different areas in Florida Bay. The South Florida Fish Habitat Assessment Program estimates benthic vegetation cover each May using a visual index of bottom occlusion within 17 basins throughout Florida Bay and along the southwest coast. The Miami-Dade Permitting, Environment, and Regulatory Affairs department estimates benthic vegetation cover quarterly in the nearshore embayments of northeastern Florida Bay using the same visual index as the South Florida Fish Habitat Assessment Program. Audubon of Florida estimates benthic vegetation percent cover every other month along transects within the mangrove lakes and creeks using a point-intercept method. A more complete description of the monitoring programs and the methodologies are presented in Chapter 12 of the 2011 SFER – Volume I.

Results

At nearly every mangrove creek monitoring site, widgeon grass cover decreased during WY2012 compared to WY2011. Cover decreased notably in Taylor River, which had experienced record high widgeon grass cover in WY2011. A decrease in cover occurred at 77 percent of the monitoring sites where widgeon grass was present in WY2011. Two transects with historically high cover had notably large decreases: on the Joe Bay transect, cover decreased from 51 to 30 percent and on the Barnes Sound transect from 35 to 15 percent. These declines are likely attributable to a late onset of the rainy season during WY2012 (Lorenz, 2011). However, widgeon grass cover did increase around Highway Creek (**Figure 6-19**). In the first quarter of

2012, a site at downstream Highway Creek had an estimated 28.5 percent cover, the highest reported since 1998. The reason for this increase is unknown.

Downstream of the mangrove creeks, in the coastal embayments and nearshore region of Florida Bay, shoal grass (*Halodule wrightii*) also showed a response to the elevated salinity in the beginning of the water year. In the first three quarters of WY2012, shoal grass declined in frequency of occurrence in nearshore sites (Trout Cove, Alligator Bay, Davis Cove, and the Mouth of Little Madeira Bay). Although shoal grass was found in 33 percent of quadrats in February–March 2011, it was reported in only 8 percent of quadrats in November–December 2011. Turtle grass (*Thalassia testudinum*) remained fairly constant through this period of declining shoal grass frequency. Turtle grass was found in 94 percent of quadrats to start WY2012 and 92 percent of quadrats in November–December of 2011.

Further into Florida Bay where sampling is done annually in May, the WY2012 results (May 2011) are more indicative of the salinity conditions experienced in WY2011 than conditions in WY2012. WY2011 was a very average year for inflows and salinity throughout Florida Bay (Sklar et al., 2012). As a result, in all monitored basins within Florida Bay, the frequency of occurrence for both shoal grass and turtle grass changed by less than 10 percentage points. For example, shoal grass in Whipray Basin went from presence in 47 percent of quadrats in May 2010 to 52 percent in May 2011. Of the 10 monitored basins within Florida Bay, only 4 had either shoal grass or turtle grass frequency of occurrence change by more than 5 percentage points.

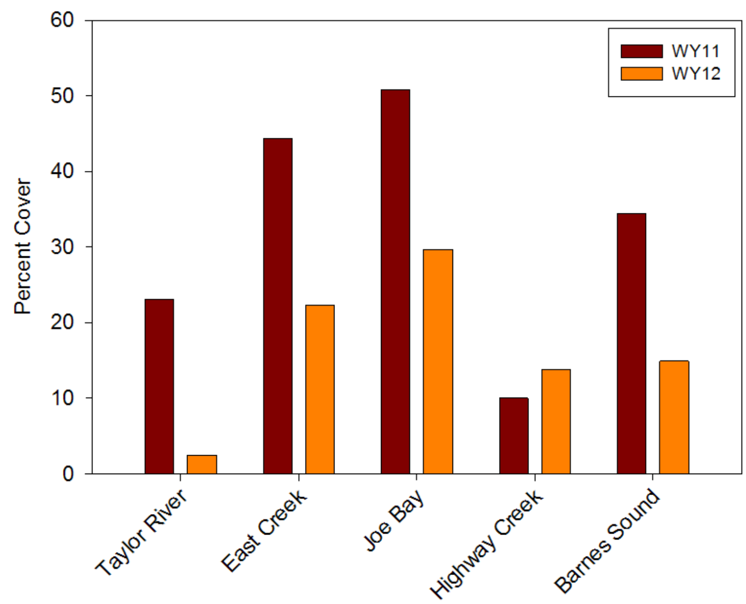

Figure 6-19. Maximum percent cover of widgeon grass (*Ruppia maritima*) during WY2012 and WY2011. Bars represent the maximum cover observed at individual sites along selected transects within each water year.

Relevance to Water Management

Elevated salinities in Florida Bay caused by high evaporation, low rainfall, and reduced creek discharge likely caused declines in seagrass habitat. Declines in widgeon grass and shoal grass, two key SAV species, are attributed to elevated salinities and a late onset of the rainy season in the early part of WY2012. This highlights the importance of the timing of the dry season/wet season transition. One of the goals of the MFL rule for Florida Bay is to prevent multiyear exceedance of salinity targets. Recovery of the SAV community will likely depend on favorable conditions in WY2013 given the MFL exceedance in WY2012.

WIDGEON GRASS LIFE HISTORY AND RECRUITMENT IN A CHANGING SALINITY ENVIRONMENT

In Florida Bay, widgeon grass is largely limited to the region of greatest salinity variability — the mangrove ecotone between the freshwater Everglades marshes and the saline bay. In this region, widgeon grass forms a critical habitat for marine and freshwater wildlife and thus is a focal species for Everglades restoration. Despite the importance of seed recruitment for widgeon grass population maintenance, seed bank viability has never been examined in Florida Bay. The factors controlling widgeon grass distribution are poorly understood and it is difficult to predict the resoibse if tge species to water management and hydrologic restoration. Widgeon grass is particularly adapted to dynamic conditions, often dominating the plant community in aquatic environments with highly variable hydrology, salinity, and water quality. This is through persistence via the "storage effect," by rapidly recruiting from the seed bank once conditions become favorable. The District and partners are engaged in a statistical analysis of long-term data relating hydrologic variables, SAV density, and prey fish density and biomass. District-funded research is also experimentally examining the effects of salinity and other factors controlling the early life history, seed germination, seedling survival, and recruitment of widgeon grass.

Methods

Strazisar et al. (2012a) conducted a series of experiments examining seed germination across a range of salinities known to occur at the ecotone (0–45 PSU) with and without low temperature (6–10°C) pretreatments. Another study (Strazisar et al., 2012b, 2012c) quantified seed densities, characteristics of the seed bank, and seed viability in transects across the Everglades–Florida Bay ecotone at sites exhibiting rapid expansion of widgeon grass reproductive shoots in the water column in northwestern Florida Bay.

Results

Ongoing surveys along six transects show that intact germinated seeds are found throughout the area between Barnes Sound and West Lake with the locus of major seedling production (both numbers of seeds per meter and percent germinated) in more western sites (**Figure 6-20**). Most germination occurs in the middle to upper (lower salinity) sites in each transect. Across this range of salinity, widgeon grass seed germination rates were low and primarily restricted to salinities less than 25 PSU. However, in a recovery phase where seeds were transferred to fresh water, high germination rates were observed in seeds previously exposed to higher salinity. A strong linear relationship exists between pre-treatment salinity and germination once salinities were lowered ($R^2 = 0.98$). These results suggest that osmotic shifts from hyper- to hyposalinity stratify widgeon grass seed coats and might explain the mechanism promoting germination when annual temperatures of the subtropical climate at the Everglades ecotone are high compared to those recognized to be required for seed stratification (≤ 6°C) in temperate climates.

In the seed bank, total seed density ranged from 150 to 1,783 per square meter along transects, the number of viable seeds in the seed bank was very low (18 seeds per square meter). Based on these data, the researchers suggest that the widgeon grass ecotone population may currently be recruitment-limited. Seed distribution varied spatially along a gradient with highest total seed densities at a western ecotone site (7,782 per square meter) to a low and non-existent seed bank (0–184 per square meter) at eastern sites.

The investigation showed that although the Everglades–Florida Bay ecotone in general has a depauperate viable seed bank, there are high density seed "hot spots" that can rapidly generate a large biomass of widgeon grass reproductive shoots, particularly in the more nutrient-enriched western ecotone region. Sediment nitrogen to phosphorus and carbon to phosphorus ratios were negatively correlated to total and germinated seeds, indicating that with higher availability of phosphorus, there is greater likelihood of plants developing to adulthood.

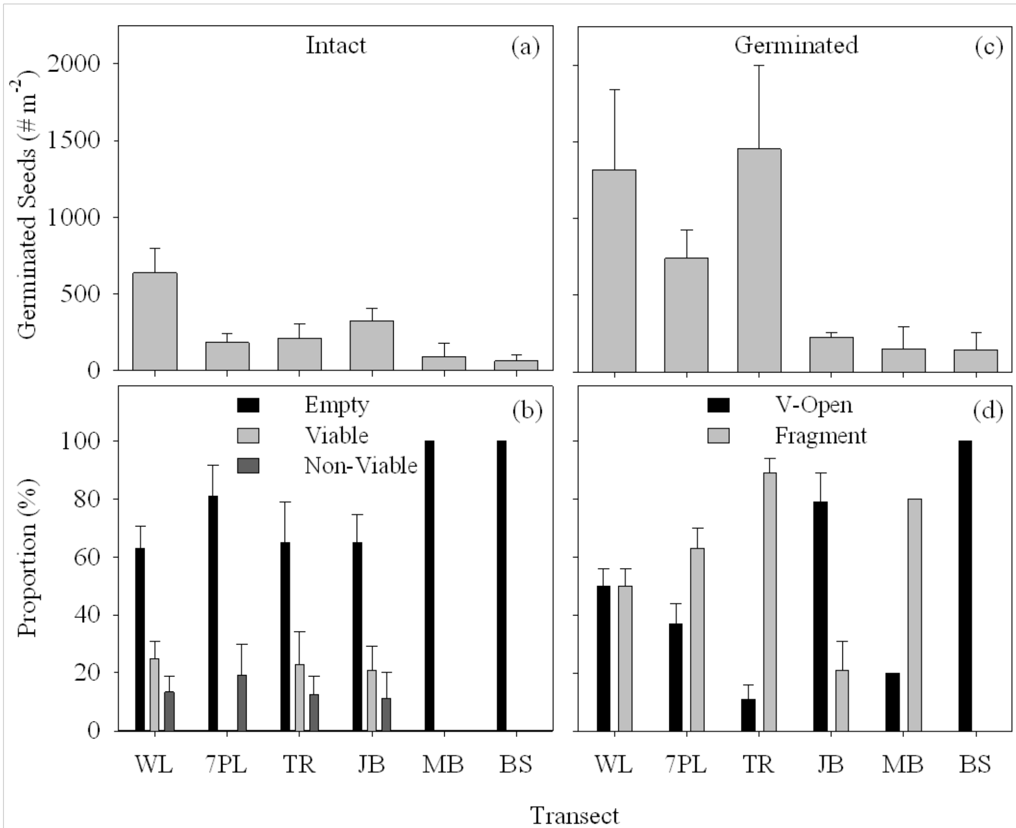

Figure 6-20. Average widgeon grass (a) intact seeds (# m^{-2} ± SE) in the seed bank across the ecotone transects and (b) the proportions (%) of those seeds that were empty or with a viable or non-viable embryo. Average (c) germinated seeds in the seed bank across the ecotone transects and (d) the proportions (%) of those seeds that were viable-open (V-open) or fragments with intact pedicels (n=40–60 cores $transect^{-1}$).

Relevance to Water Management

A primary focus of the MFL rule and of recent research in Florida Bay is on the freshwater widgeon grass community and the freshwater macroalgae consortium (e.g., *Chara* sp.) that historically provided high quality habitat in the variable salinity mangrove transition zone. The MFL rule is designed to protect the seagrass resources in northern Florida Bay. For the 2012 MFL update, the effectiveness of the current rule is being evaluated through field monitoring of seagrass and macroalgae and ecosystem simulation modeling. Trends in widgeon grass cover are important because the species is an indicator of the ecological status of the transition zone and is identified as the valued ecosystem component being protected by the Florida Bay MFL rule. Because the salinity variable affects many seagrass communities (though not species) in similar fashion, widgeon grass cover often tracks trends in total SAV cover in the larger bay landscape (Frezza et al., 2011). It is important to know the conditions required to successfully germinate widgeon grass seeds and promote seedling survival to recruit new adult plants, which is a performance measure for the CERP C-111 project. It was determined that seed germination was enhanced by pre-conditioning from the variable salinities experienced in the ecotone, but freshwater conditions were required for germination; relatively low salinities fostered rapid seedling development to adults.

ECOSYSTEM ECOLOGY

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This section focuses on two regions. The first is WCA-2A, which has been severely impacted by nutrient enrichment, and preliminary results of two new Active Marsh Improvement projects designed to restore ecosystem function to areas currently influenced by cattail (*Typha domingensis*) invasion are presented. The second is the region containing the coastal communities of the Florida Bay area that is monitored as part of the C-111 Spreader Canal Western Project. A major CERP restoration project, the C-111 Spreader Canal Western Project was completed in WY2012 and is expected to be operational in WY2013.

ACTIVE MARSH IMPROVEMENT PROJECTS

Restoration of phosphorus-impacted regions of the Everglades requires not only a reduction in phosphorus loads and concentrations, but also active management efforts to reduce the resilience and resistance inherent to the cattail regime (Hagerthey et al., 2008). The Cattail Habitat Improvement Project (CHIP) was a large-scale in situ study designed to test the ability to rehabilitate slough habitat in cattail areas by creating an alternative SAV regime. Open areas were created in enriched and moderately-enriched (i.e., transitional) areas of WCA-2A in July 2006. Triplicate plots were designated as enriched open (EO)/enriched control (EC) or transitional open (TO)/transitional control (TC) based on their location along the nutrient gradient and numbered 1 through 3, with 1 being the most westerly and 3 the most easterly plot. Completed in 2009, this project demonstrated that created openings maintained higher dissolved oxygen concentrations, SAV/periphyton became the dominant vegetation community, small fish species rather than crayfish dominated the aquatic faunal biomass, and wading bird foraging was extensive. Important issues regarding how to actively improve habitat conditions were identified during CHIP. They are associated with (1) hydrologic interactions on vegetation community and cattail reinvasion development, (2) the importance of spatial heterogeneity of the habitat and vegetated edges for wading bird foraging, and (3) the limitation of using broad spectrum herbicides on vegetation succession.

First, throughout the duration of the CHIP study, there were distinct differences in the rate and extent of cattail reinvasion of the created open plots, dependent on their location along a west-east gradient. For example, vegetative cover estimates collected in September 2009 demonstrated that emergent macrophyte cover (principally cattail) increased to 2, 3, and 11 percent within plots EO1, EO2, and EO3, which are arranged west to east, respectively. SAV cover was 98, 96, and 80 percent in the same plots. Similar west-east differences in the extent of cattail reinvasion were observed for TO plots. While active sampling of the CHIP plots ended in 2009, aerial reconnaissance continued. Recent imagery shows continued evidence of the east-west preference for cattail growth, with the western four plots (EO1, EO2, TO1, TO2) having limited growth, but significant invasion of the eastern plots (**Figure 6-21**).

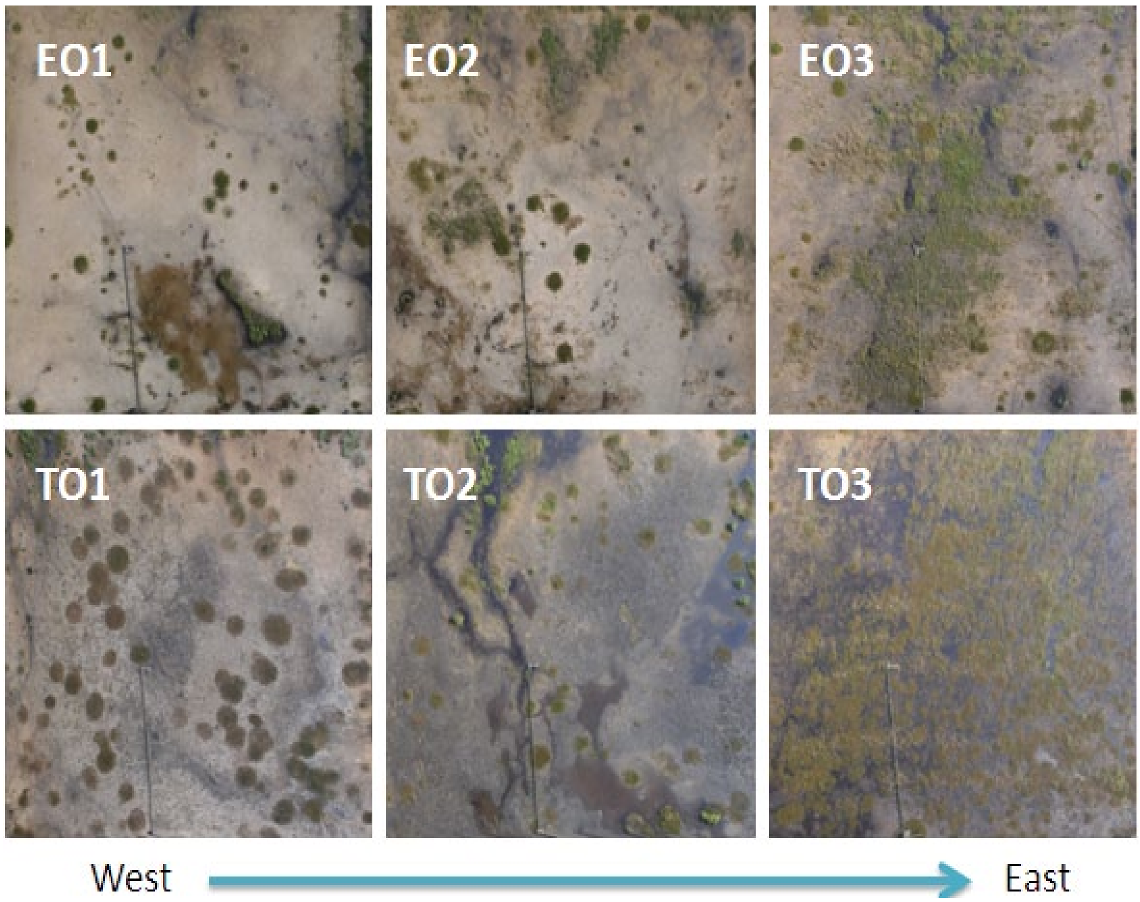

Figure 6-21. Aerial photographs of Cattail Habitat Improvement Project (CHIP) open plots obtained in April 2012 during a dryout. When wet, open water/ muskgrass areas (whitish zone) and spikerush stands (greenish-tan circular areas) dominate enriched open plots (EO1, EO2) and transitional open plots (TO1, TO2). The diffuse green areas in EO3 and TO3 are a combination of spikerush, cattail, and other emergent vegetation.

Several studies have found that when nutrients are abundant, cattail is more competitive under deeper water conditions (Newman et al., 1996; Newman et al., 1998). While the nutrient content of the CHIP plots were similar, water depth data indicate that there was a west-east hydrologic gradient, with western plots experiencing a more rapid and greater degree of dryout, while eastern plots generally experienced longer hydroperiods and deeper water levels (**Figure 6-22**). Thus an important consideration in minimizing the amount of herbicide applied and the self sustainability of habitat improvement strategies is to understand how local hydrologic conditions, both flooding and dryouts, influence the interaction between hydrologic stress and herbicide efficacy on cattail and therefore the rate and extent of cattail reinvasion.

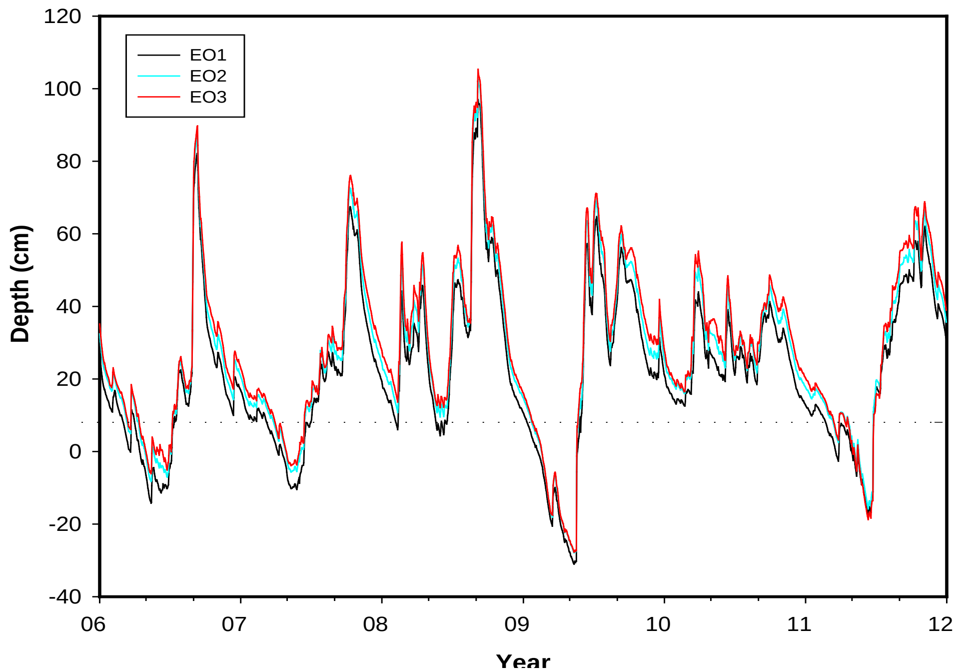

Figure 6-22. Water depths modeled from the Water Depth Assessment Tool (WDAT) showing west-east (EO1-EO3) hydrologic gradients experienced by enriched open plots within CHIP from 2006–2012.

A second major issue is that certain wading bird species (e.g., white ibis) tended to forage along the edges of the CHIP open plots, at the interface between the created opening and dense cattail, rather than in the center of the plots. Whether this was due to locally greater prey availability, greater prey diversity due to the habitat mosaic, or alternate reasons is unknown. Moreover, it is unknown how vegetation succession within the open plots influences this response. Understanding the significance of habitat edges is important to understanding how to plan created openings for larger ecosystem restoration, for example, is it important to create a mosaic of vegetated and open plots that optimizes the ratio of edges to open water? Such understanding is also imperative when considering the more general restoration of the Everglades ridge and slough landscape.

Third, while the combination of glyphosate and imazapyr effectively controls cattail, which after the initial treatments during the first 16 months required no retreatment for three years, these are broad spectrum herbicides that killed all the herbaceous vegetation. Thus vegetation succession is set back each time herbicides are applied. However, recently, Rodgers and Black (in press) demonstrated that aerial application of imazamox [0.28 kilograms acid equivalent per hectare (kg ae/ha)] provided excellent control of cattail in minimally invaded marsh and slough habitat, with little damage to emergent species or SAV. While the cattail response observed by Rodgers and Black (in press) is based on results one-year after treatment, the apparent specificity of imazamox may allow cattail management with less damage to other species. It could therefore increase the ability to rehabilitate and restore nutrient enriched areas of the Everglades. However, before broad-scale application of this herbicide is implemented, additional studies need to be undertaken, including the determination of the optimum application rate and assessment of damage to native Everglades species not present in the Rodgers and Black (in press) plots.

The questions associated with the interaction of herbicide effectiveness and hydrologic conditions on plant growth, and habitat edge contributions to foraging wading birds, were integrated into the experimental design of two large-scale studies. Because the primary objective is to facilitate landscape recovery/improvement in areas currently impacted by nutrients, these projects are called Active Marsh Improvement (AMI).

Ridge and Slough Landscape Restoration Study

The large-scale AMI ridge and slough landscape restoration study (AMI-1) builds upon CHIP by conducting active marsh manipulation at a large scale. This study aims to determine whether active marsh restoration techniques can restore ridge and slough patterning and structure within nutrient-enriched cattail areas. The treatments are expected to allow for a greater diversity of vegetation and habitats compared to CHIP plots such that vegetation communities and the historical structural patterning of sawgrass ridges and open water sloughs are retained. Within this general framework, researchers can assess wading bird usage and the importance of edges for foraging, and secondly study the significance of the west-east gradient in hydrology that appears to control the rate and extent of cattail reinvasion.

Methods

Two 750 m x 500 m plots were established in a nutrient-enriched area of WCA-2A along the west-east hydrologic gradient (AMI west and AMI east; **Figure 6-23**). Plots were aerially sprayed in April 2011 with imazamox at a rate of 0.28 kg ae/ha and burned in January 2012. Imazamox was used to limit cattail return while allowing more rapid recovery and succession by desirable vegetation following the burn.

Total vegetative cover is quantified annually via oblique aerial photos taken at approximately 500 ft altitude and georectified to reduce spatial distortion. The resulting images are sub-divided into 6.25 m x 6.25 m boxes where the categories of emergent vegetation, SAV, open water, or woody vegetation are assessed resulting in frequency and percentage occupied per plot. In addition, twelve 100 m belt transects are used to capture species occurrence throughout the spatial extent of each plot. Three 2 m x 0.5 m quadrats per belt transect are used to quantify percent total vegetative and non-vegetative cover, species relative percent cover, percent composition, density, and frequency of occurrence. Measurements will be repeated annually.

Aerial photography will be the primary tool used for wading bird surveys and wildlife data analyses. Photographs of wading birds within the AMI plots and across reference areas when water depths are suitable for foraging will be taken from November–April during weekly systematic reconnaissance flights. Photographs will both confirm species identifications and bird numbers, and will facilitate species-specific mapping. For the mapping application, georeferenced photographs will be analyzed to calculate a variety of spatial statistics, including distance to managed edges, correlation amongst spatial layers (e.g., vegetation, water depth, bird distribution), and to test observed distribution patterns against a “null” spatial model of random distribution. A series of verification exercises in early WY2013 are planned to ensure these novel techniques will capture data within an acceptable margin of spatial error to reliably estimate bird locations (in relation to edge distances) within these two plots. If the wading bird data demonstrate spatial patterning, work in subsequent years will also assess mechanisms to explain observed distributions, especially as they relate to prey density and availability.

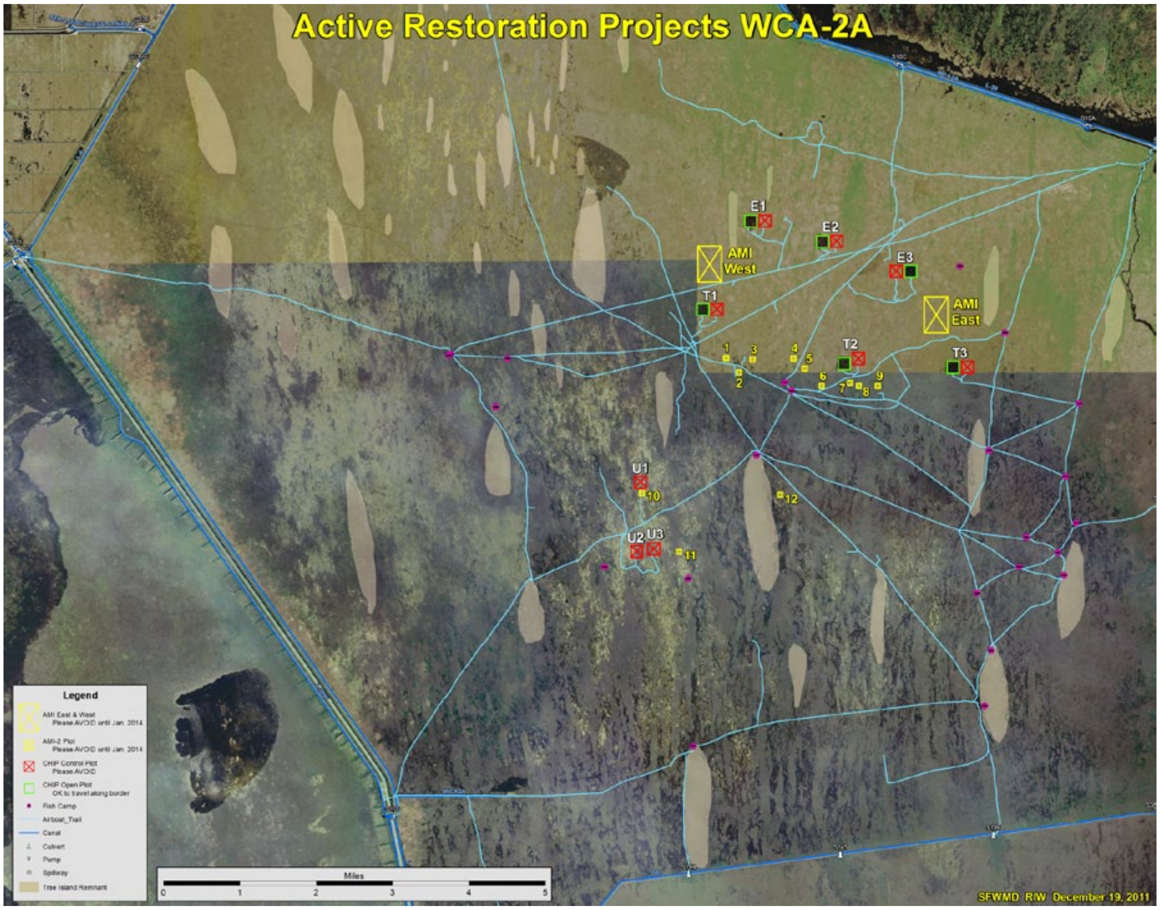

Figure 6-23. Location of Active Marsh Improvement (AMI) projects, AMI-1 (yellow rectangles) and AMI-2 (smaller yellow squares), in WCA-2A. CHIP plots (red squares) are included for reference and to show them relative to the west-east gradient observed in CHIP data.

Results and Discussion

Preliminary vegetation surveys indicated that west and east plots were similar in vegetative cover (**Table 6-4**). Most cover was emergent dead vegetation, with only 26–34 percent of cover live vegetation. Most individual species accounted for less than 1 percent of the total, with the exception of sawgrass (*Cladium jamaicense*) and cattail. Sawgrass comprised 11 and 20 percent of live cover in the west and east plots, respectively, compared to 10 and 11 percent observed for cattail.

Species distribution was similar between sites and as expected, sawgrass and cattail were dominant in both plots (**Table 6-5**). Coastal plain willow (*Salix caroliniana*) and buttonbush (*Cephalanthus occidentalis*) were also frequently observed. Vines are a common component of nutrient enriched, highly disturbed areas of the Everglades. For the study area, climbing hempvine (*Mikania scandens*) was the primary vine found in the east plot, while white twinevine (*Sarcostemma clausum*) was more frequently observed in the west plot.

Within 1.5 months after treatment (MAT) the selectively of imazamox was evident; cattail was senescing, while other species showed limited damage (**Figure 6-24**).

Immediately following the burn in January 2012, both plots experienced extensive wading bird foraging activity. Bird numbers peaked two weeks post-burn in the eastern plot (649 birds) and six weeks post-burn in the western plot (493 birds); large numbers (>240 birds) continued to forage in both plots until seven weeks post-burn, after which the plots dried and bird numbers dropped on average by an order of magnitude. White ibis were the dominant species during this peak foraging period, comprising 78–94 percent of birds. Interestingly, at the same time, the CHIP plots were being heavily utilized by glossy ibis (*Plegadis falcinellus*) and piscivorous herons and egrets, but very few white ibis. This may suggest differences in prey resources in these different habitats.

Aerial imagery of the plots from June 2012 indicates that while there is extensive sawgrass and other species present, both plots have experienced rapid regrowth of cattail. In comparison, Rodgers and Black (in press) applied the herbicide treatment in September and observed successful cattail control 12 MAT. The regrowth observed in the AMI-1 plots may be attributable to the herbicide application occurring in April. Optimal herbicide efficiency for cattail occurs if plants are treated when translocation of carbohydrate reserves, and consequently herbicide, to rhizomes is greatest (Linz and Homan, 2011). Comparing these results with the upcoming 12 MAT sampling for AMI-2 (October 2012) will help identify the most effective time to treat cattail and then these AMI-1 plots will be resprayed.

Table 6-4. Percent cover of vegetative habitats based on quadrat sampling (1 m^2) in AMI-1 plots.

Habitat Type	West	East
Emergent Vegetation- live	19	26
Emergent Vegetation-dead	74	65
SAV	0	0
Open Water	7	8

Table 6-5. Frequency of species occurrence (%) determined using 100 m belt transects in AMI-1 plots (n=12 per plot).

Species	***West***	***East***
Leatherfern *(Acrostichum danaeifolium)*	58	0
Southern water hemp *(Amaranthus australis)*	0	8
Buttonbush *(Cephalanthus occidentalis)*	75	42
Muskgrass *(Chara* sp.)	8	0
Sawgrass *(Cladium jamaicense)*	100	100
Swamp lily *(Crinum americanum)*	17	25
Knotted spikerush *(Eleocharis interstincta)*	0	8
Climbing hempvine *(Mikania scandens)*	0	42
Non-calcareous algae	75	50
Fragrant water lily *(Nymphaea odorata)*	17	8
Smartweed *(Persicaria* spp.)	67	33
Arrowhead *(Sagittaria lancifolia)*	42	100
Coastal plain willow *(Salix caroliniana)*	75	92
White twinevine *(Sarcostemma clausum)*	50	17
Softstem bulrush *(Schoenoplectus tabernaemontani)*	25	0
Bulrush *(Schoenoplectus* sp.)	17	0
Cattail *(Typha domingensis)*	100	100

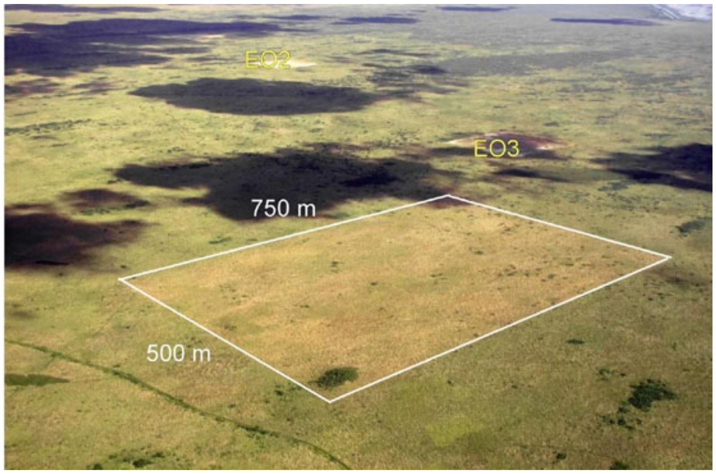

Figure 6-24. Aerial photograph of AMI-1 east plot taken December 2011. Senescing cattail are shown as the yellowish color, willow heads are dark green topographic highs, and the lighter green dispersed throughout the plot is sawgrass. CHIP plots are labeled for scale and location reference.

Slough Study

The objective of the slough study (AMI-2) is to reduce the extent of cattail at the leading edge of the nutrient front in WCA-2A, thus reestablishing open water sloughs free of dense cattail stands and determine which species will immigrate to these areas with the removal of cattail competition. To minimize the application of herbicides in the Everglades, this study was also designed to determine the minimum effective dosage rate of imazamox to manage cattail while limiting the detrimental effects to desirable emergent, floating, and submerged plants.

Methods

Nine 100 m x 100 m plots with either one of two herbicide treatments being studied or under control conditions were established in a randomized block design at three locations along the southernmost extent of the nutrient enrichment gradient, i.e., cattail front, in WCA-2A (**Figure 6-23**). A block design was used to account for the west-east hydrologic gradient observed in CHIP. All plots contained similar proportions of ridge and slough habitat. Two herbicide treatments, 0.21 or 0.28 kg ae/ha (24 or 32 ounces per acre) of imazamox, were applied in October 2011. To assess whether vegetative recruitment, species, and density will be similar to nutrient unimpacted areas, three 100 m x 100 m reference plots were also established downstream in areas with no cattail invasion.

Each plot was divided into 16 sections in which six ridge and six slough vegetation sampling sites were randomly located. At each location, a 2 m x 0.5 m quadrat was used to assess total vegetation cover, open water/bare ground cover, percent species relative cover, percent composition, density, and frequency prior to herbicide application. These variables will be reassessed in all plots at 12, 24, and 36 MAT. Within each treated and control plot, individual plants representing a broad spectrum of the flora were tagged and rated in terms of herbicide control at 3 and 6 MAT. A final herbicide rating of tagged plants is planned for 12 MAT.

Total vegetative cover is being quantified via oblique aerial photographs collected annually at approximately 500 ft altitude. Each photograph will be sub-divided into a 10 m x 10 m spatial resolution and assessed for emergent vegetation, SAV, open water, and woody vegetation frequency of occurrence and percentage area occupied.

Results and Discussion

At 3 and 6 MAT, each tagged plant was revisited and ranked according to the degree of herbicide damage. Rankings were Alive (normal growth with no visible phytotoxic effect), Resprout/Healthy (defoliated with healthy resprout), Alive/Injury (herbicide damage evident but plant alive), or Dead (only dead leaves/cambium observed). Results from 6 MAT (**Table 6-6**) indicate that cattail and arrowhead (*Sagittaria lancifolia*) were the most sensitive to the herbicide treatments, with 100 and 50 percent death, respectively at the highest dose. In general, herbicide effects were not present or less evident at the lower of the two doses for all species assessed.

Some effects of herbicide damage were more subtle than others. For example, a key distinction between treated and untreated sawgrass was the greatly reduced incidence of flowering, while water lily expressed crimped leaves. One species, coastal plain willow, exhibited highly variable symptoms ranging from stunted or deformed leaves to no visual damage.

These results are preliminary and the 12 MAT assessment of herbicide efficacy and plant community response will provide a more complete evaluation of the herbicide treatments. Plant survival of tagged plants is expected to be similar to that observed at 6 MAT. Percent cover of species within each quadrat will be compared for each habitat type (ridge and slough) between treatment and controls, with the trajectory of slough restoration assessed by comparing to unenriched reference sites. Reinvasion of treated plots will be assessed annually so long-term sustainability of the plots can be determined.

Table 6-6. Evidence of herbicide damage on cattail and other more desirable native species six months after treatment (MAT). Values are percentage of tagged species.

	Herbicide Treatment					
	0.21 kg ae/ha#			0.28 kg ae/ha#		
Species	Alive*	Injury	Dead	Alive*	Injury	Dead
Cattail	24	6	71			100
Muskgrass	100			79		21
Sawgrass	94	6		79	21	
Spikerush[1]	100			92	8	
Fragrant water lily	100			61	22	17
Smartweed	100			100		
Arrowhead	50	17	33	42	8	50
Coastal plain willow	100			56	38	6
Leafy bladderwort[2]	100			86		14

kg ae/ha = kilograms acid equivalent per hectare
*Alive = combination of alive + resprout/healthy
[1]*Eleocharis cellulosa*, [2]*Utricularia foliosa*

Relevance to Water Management

While nutrient loads to the Everglades have been reduced, the downstream ecosystem is resilient and resists change. As reported in previous SFERs, the results from CHIP demonstrated that managing vegetation can create alternate regimes, which alter biogeochemical cycling and provide foraging areas for wading birds in areas previously inaccessible. However, the herbicides used were broad spectrum, thus desirable vegetation, in addition to cattail, were damaged or killed when areas were resprayed. A recent study (Rodgers and Black, in press) indicates that the CHIP approach may be improved upon by using an herbicide that appears selective towards cattail. Preliminary observations from AMI-1 and AMI-2 indicate that the time of year when herbicide treatment is applied has a significant impact on subsequent cattail reinvasion. In addition, CHIP results highlighted the interaction between hydrology and cattail reinvasion. Further study will help optimize vegetation management and ecosystem restoration by providing critical information on the selectivity of imazamox, the frequency of application for large-scale management, the relationship between hydrology and reinvasion, and the spatial dynamics for optimal wading bird foraging.

CHANGES IN PLANT COMMUNITY STRUCTURE IN EVERGLADES NATIONAL PARK TREE ISLANDS

Tree islands, integral components of the ridge and slough landscape that characterize the Everglades, are complex ecosystems that include different plant communities: tropical hardwood (hammock), bayhead, and bayhead swamp forests arranged along topographic, hydrologic, and soil fertility gradients (Ross et al., 2006; Espinar et al., 2011). Along these physico-chemical gradients, species composition also varies, with flood-intolerant woody species dominating the highest elevated portion of tree islands and flood-tolerant species, including graminoids (grasses) or broad-leaved submerged species dominating the lowest elevations. Thus, physico-chemical drivers produce a range of woody assemblages that vary in species composition and life-form structure, represented in the proportion of plant growth forms that are present.

Among physico-chemical factors, topography and hydrology are two of the most important drivers of species differences within individual tree islands and among various types of tree islands in the Everglades (Armentano et al., 2002; Wetzel et al., 2008). On tree islands, the swamp forests and tails are usually the areas that respond most noticeably to hydrology, whereas on an interannual scale, the response of the tree island heads to windstorms overshadows any detectable hydrologic response (Ruiz et al., 2011; Sah et al., 2011). However, substantial changes in hydrological conditions, whether natural or man-induced, are likely to affect tree island forest structure and composition to some extent. In this sense, extreme and prolonged wet or dry events could lead to complete forest structure degradation and changes in tree island ecological function.

This study examines the spatio-temporal variation in vegetation composition along environmental gradients on tree islands within the northeastern Shark River region. The main objectives of this study are (1) quantifying species and growth form distribution along the environmental gradient, (2) quantifying boundaries of vegetation assemblages, and (3) assessing the response of species composition and life forms to temporal changes in the hydrologic regime.

Methods

The study was conducted on three tree islands, Black Hammock (BL), Gumbo Limbo (GL), and Satinleaf (SL), which are organized around a slightly elevated limestone outcrop with a well-defined "head" that supports a mixture of flood-intolerant woody species and a "tail" that, at its upper end, is dominated by flood-tolerant species and further downstream by tall sawgrass.

In 2001 and 2011, the plant community was sampled along four transects on each tree island. One transect followed each island's long axis (north-south or NS) and the other three were in the west-east direction. Of the west-east transects, one traversed the head (hammock), one traversed the middle (bayhead), and the third traversed lower (bayhead swamp) portions of the islands. Vegetation was sampled along each transect, including an estimate of the maximum height and cover class of trees and vines by species within a 2 m radius plot; and an estimate of cover class of herbs and shrubs by species within a 1 m radius plot. Vegetation was sampled every 5 to 10 m along each transect. A split moving-window (SMW) boundary analysis (Cornelius and Reynolds, 1991) was used to describe the variation in vegetation composition and to identify boundaries between vegetation assemblages along transects. The mean cover of each life form (i.e., trees, shrubs, graminoids, forbs, ferns, vines, seedlings) at each sampling point was used to calculate the Bray-Curtis dissimilarity. Finally, the beta diversity ($\beta = \gamma/\alpha$) was calculated to examine the change in species diversity between the tree islands over time.

Results

Vegetation composition follows the north-south topographic gradient that runs parallel to the direction of the water flow. The SMW boundary analysis of the 2001–2002 species cover data along the north-south transects identified two or three significant peaks, represented by a high normalized Brady-Curtis dissimilarity (z-scores > 1.65), resulting in three or four distinct vegetation assemblages, including hardwood hammock, bayhead, bayhead swamp, and the marsh vegetation at the far end of each transect. However, the number and sharpness of significant peaks differed among tree islands, suggesting that the level of distinction between vegetation assemblages and species turnover along the gradient are not the same on all tree islands. For instance, on Gumbo Limbo, three significant peaks resulted in four distinct plant communities: hardwood hammock, bayhead, bayhead swamp, and sawgrass marsh (**Figure 6-25**). On Satinleaf, an analysis based on life form abundance revealed three significant peaks, denoting the same four plant communities. On Black Hammock, the boundary separating two types of swamp forests was not distinct for either the compositional or the life form analysis. In general, the sharpness of peaks separating adjacent vegetation assemblages was more distinct on Gumbo Limbo than on Black Hammock and Satinleaf islands.

The β-diversity, which is a measure of change of species diversity over time, differed significantly ($p < 0.05$) among the three habitat zones (hardwood hammock, bayhead, and bayhead swamp transects). Similarly, β-diversity was significantly higher for the hardwood hammock transects than on the bayhead swamps; however, β-diversity for the bayhead transects was similar to either the hardwood hammock or bayhead swamp transects (**Figure 6-26**). Finally, across all transects, β-diversity was significantly higher ($p < 0.001$) in 2011 than in 2001, suggesting greater microhabitat heterogeneity.

Discussion

Physical factors, including topography, water depth, and soil nutrients, that influence the position of the boundaries among adjacent communities are likely to be the same that affect the distributions of individual species. In this sense, the spatial heterogeneity hypothesis suggests that the greater the habitat heterogeneity, the higher the coexistence of diverse species (Davidowitz and Rosenzweig, 1998; Kumar et al., 2006). Thus, along an environmental gradient, a positive relationship between habitat heterogeneity and degree of species turnover is expected. Generally, in periodically flooded ecosystems such as floodplains, continuous flooding and high water levels are known to form a homogeneous habitat, whereas during low water level, habitat heterogeneity increases (Thomaz et al., 2007). In contrast, a fluctuating water level with a periodic drydown is likely to increase habitat heterogeneity, especially in topographically heterogeneous areas. On the studied tree islands, a positive relationship was observed between the normalized Brady-Curtis dissimilarity and habitat heterogeneity, suggesting that processes that enhance habitat heterogeneity along the environmental gradient have produced zones of high species turnover. Moreover, β-diversity was higher in 2011 than 2001, suggesting that resource heterogeneity on the tree islands has increased over the last 10 years, which could be due to both relatively dry conditions and interannual variability in water depth. Similarly, over the last decade, while the life form composition of some of these assemblages changed in response to interacting environmental drivers, including hydrology and disturbances (fire and storms), it was observed only on a few transects. In general, shifts in boundaries among plant communities are presumed to initiate reductions in ecosystem resilience, resulting in regime shifts. However, on these tree islands, the effect of annual variation in hydrology over the previous decade probably did not surpass the ecosystem's resilience, hence a minimal shift in the boundary between vegetation assemblages was observed on most transects.

Relevance to Water Management

The desired restoration conditions for Everglades tree islands are to improve the health of those that are considered to be stressed or degraded, and to prevent the loss of tree island heterogeneity due to exposure to extreme (either long or short) hydroperiods. Results from this project indicate that tree island plant diversity and resilience are greatly linked to a fluctuating hydrology; thus giving flexibility to the management of water levels in the Everglades. However, researchers still need to provide thresholds for extreme events (either high or low water levels) so that tree island resilience is enhanced.

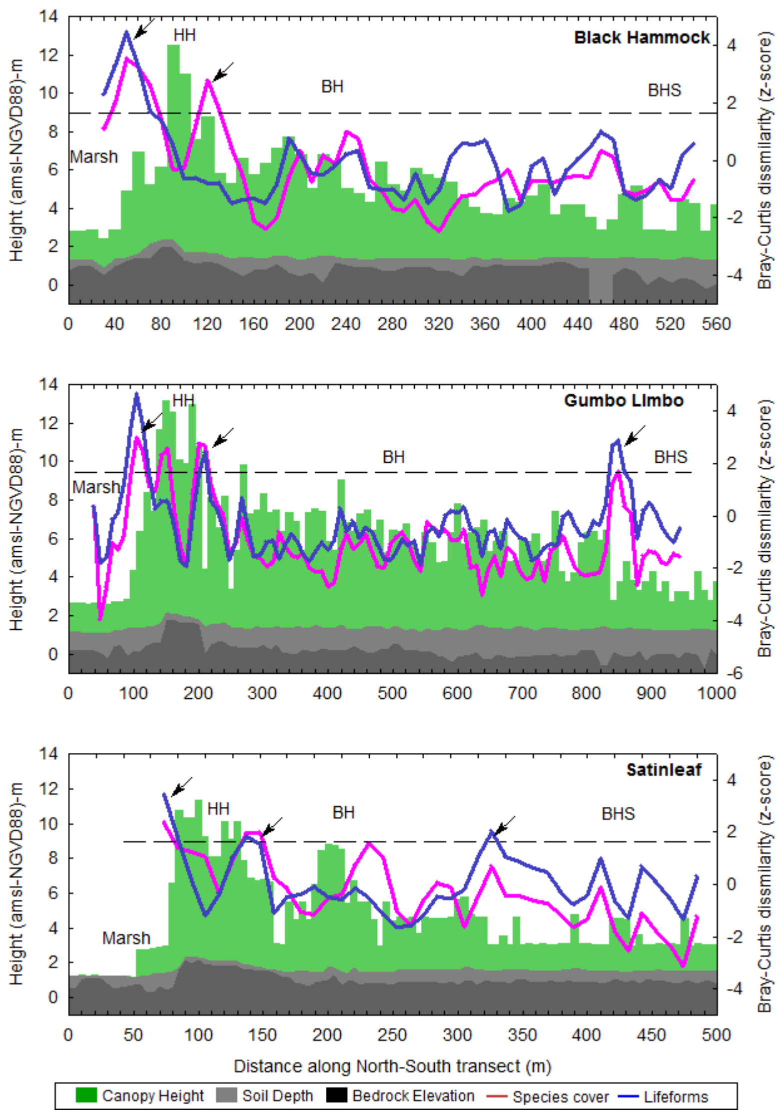

Figure 6-25. Canopy height, bedrock elevation, soil depth, and normalized Bray-Curtis dissimilarity (z-scores) based on species cover and life form cover along north-south transects on three tree islands within the northeastern Shark River Slough region (HH=hardwood hammock, BH=bayhead, BHS=bayhead swamp).

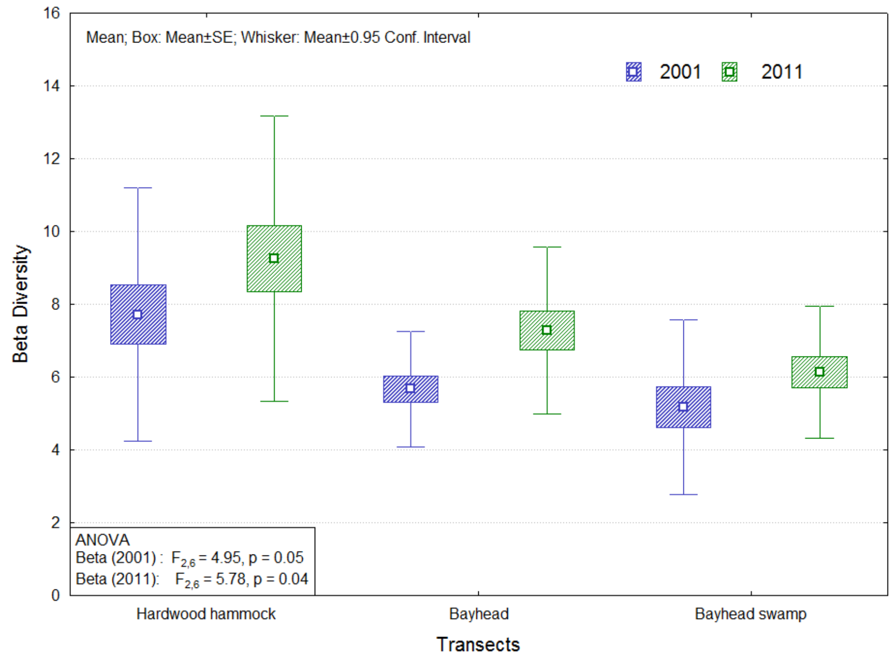

Figure 6-26. Box-plots showing the mean (±SE) of beta diversity (β) in 2001 and 2011 on the transects that crossed the head (hardwood hammock), middle (bayhead), and lower (bayhead swamp) portions of Shark River Slough tree islands.

FLORIDA BAY WATER QUALITY AND ECOHYDROLOGY

Florida Bay Water Quality Conditions and Status

Water quality in Florida Bay and other southern coastal systems has been monitored since 1991 (WY1992) to ensure that District operations and projects protect and restore the ecosystem to the extent possible. CERP performance measures focus on chlorophyll *a* concentration (Chl*a*), an indicator of algal blooms, as well as the nutrient inputs that initiate and sustain blooms. A major CERP restoration project, the C-111 Spreader Canal Western Project, was completed during WY2012, though operations are not scheduled to begin until WY2013. The primary objective of the project is to minimize seepage from Taylor Slough toward the east and the C-111 basin. Retaining more water in Taylor Slough will facilitate more natural patterns of flow, timing, and freshwater distribution to sustain ecosystem structure and function in the southeast Everglades and Florida Bay. These hydrologic modifications are not expected to alter downstream water quality characteristics, but any degradation of water quality could constrain restoration. Project constraints call for no increase in the magnitude, duration, or spatial extent of algal blooms.

Results of water quality monitoring in Florida Bay and the coastal systems to the west (Whitewater Bay) and east (Barnes Sound in Biscayne Bay) are reported here. These estuarine regions have distinct water quality and ecological characteristics, in part a consequence of the differential inputs of water and associated materials from the Everglades: Shark River Slough discharging into Whitewater Bay in the west and the C-111 canal discharging into Barnes Sound in the east. Changing operations associated with implementation of the C-111 South Dade Project, Modified Water Deliveries to ENP (especially Tamiami Trail modifications), and the C-111 Spreader Canal Western Project will further change freshwater flow patterns and may alter water quality. This section compares WY2011 and WY2012 water quality to the temporal median of the monthly spatial means and the interquartile range (IQR) for the entire period of record.

Methods

Water samples and physical parameters (temperature, salinity, conductivity, pH, and dissolved oxygen) are collected monthly in Barnes Sound and every other month at all other sites. Samples are collected at 0.5 m below the surface and processed according to the SFWMD Field Sampling Quality Manual following Florida Department of Environmental Protection (FDEP) protocols. Physical parameters are collected with a calibrated sonde following SFWMD protocols. Samples are processed on site, stored on ice, and shipped overnight to the SFWMD Analytical Lab in West Palm Beach for analysis according to SFWMD Laboratory Quality Manual following FDEP protocols. All samples are quality assured before being uploaded to the District's DBHYDRO database. In October 2011, the monitoring network sampling frequency in all areas except Barnes Sound was changed from monthly to every other month. At the time of this analysis, the April 2012 data were not available except for Barnes Sound, resulting in only eight months of data for this summary.

Results and Discussion

Chlorophyll *a* concentrations exhibited mixed and variable results across regions (**Figure 6-27** and **6-28**). In the east, there were two peaks in Chl*a* (August and December 2011). These peaks were well below the RECOVER water quality performance measure upper range of 2 micrograms per liter (µg/L) for this region. The December peak may have resulted from resuspension of benthic chlorophyll as turbidity was very high [23 nephelometric turbidity units (ntu)], twice as high as the 75th IQR. In the western region, a Chl*a* peak in August was almost twice as high as the 2 µg/L upper range performance measure limit, and during the wet season remained higher than the long-term median before declining in the dry season. The central bay was at or below the long-term median for the entire water year. In Whitewater Bay, Chl*a* concentrations were below the long-term median during the wet season and well above the median for the entire dry season with a peak in December 2011 (8 µg/L). Finally, in Barnes Sound, peaks in Chl*a* concentrations occurred in August and October 2011 and in March 2012, well above the 75th IQR, but still below the performance measure upper range of 2 µg/L. None of the peaks in any regions, except possibly the December peak in the east mentioned above, were correlated to any other water quality parameters measured at the same time.

Total phosphorus (TP) concentrations in all regions, except the western region during the dry season, continued to be less than the long-term median and often less than or equal to the 25th IQR for the entire water year (**Figure 6-29** and **6-30**). Total nitrogen (TN) had the opposite trend, being greater than the long-term median and often greater than the 75th IQR for the entire water year except in Barnes Sound where TN was at or below the 25th IQR except for peaks in September and October 2011 (data not shown). The reasons for these trends are unclear, but not unprecedented in the region. Abbott et al. (2005) evaluated long-term (1991–2003) water quality data at 13 sites throughout the Biscayne Bay watershed and found that nitrogen concentrations were generally increasing and TP concentrations were declining over this period. In most areas, annual average concentrations of all of the water quality parameters measured (TP, TN, Chl*a*, total organic carbon, dissolved inorganic nitrogen, turbidity) have stabilized during the last three water years. The notable exception is the dissolved inorganic nitrogen in Barnes Sound, which has continued to increase slightly since WY2008.

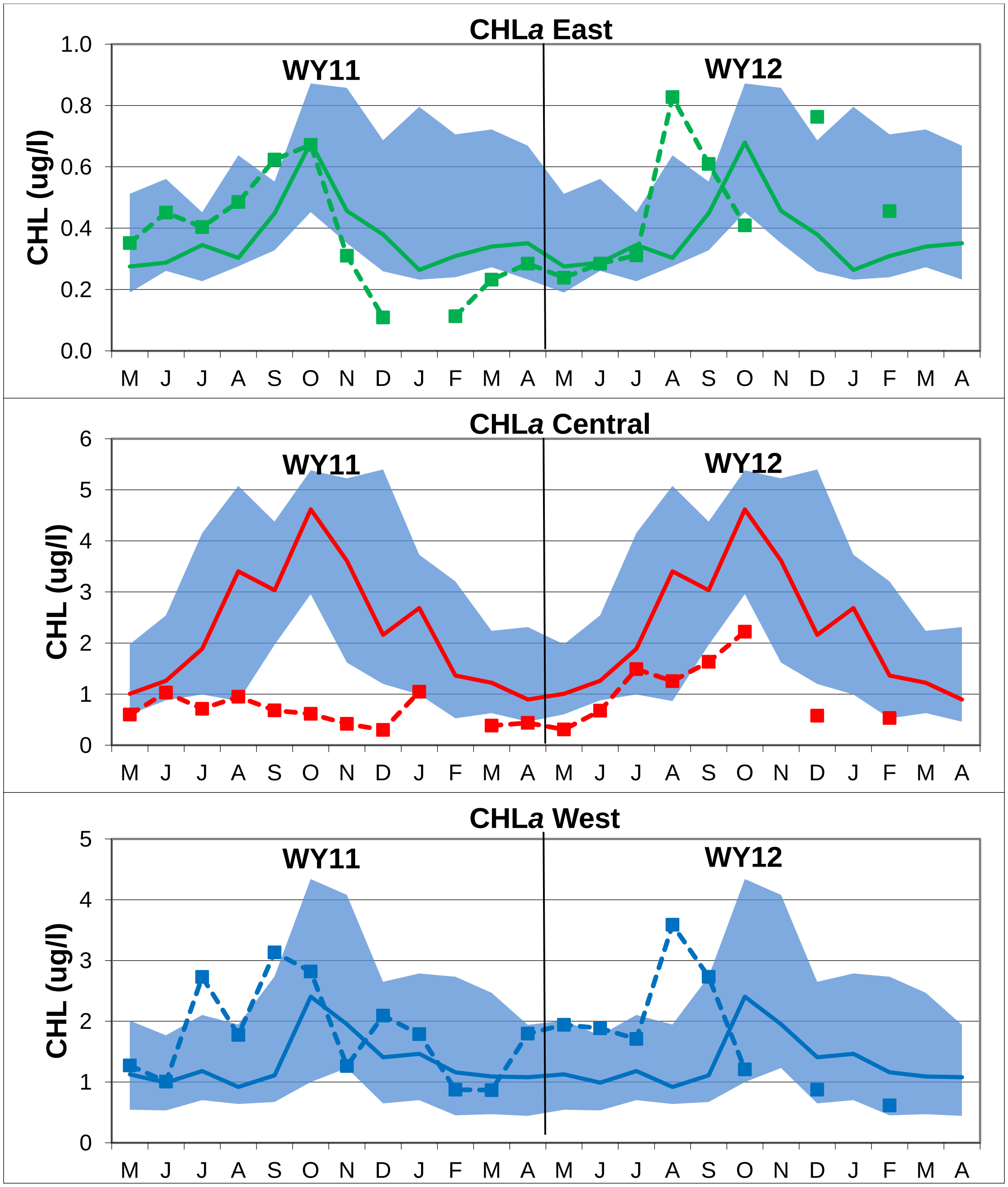

Figure 6-27. Monthly chlorophyll *a* (Chl*a*) concentrations in micrograms per liter (µg/L) in three regions of Florida Bay during WY2011 and WY2012 (dashed line with solid symbols) compared to median and interquartile range of monthly means from WY1992–WY2010 (solid line and blue shading).

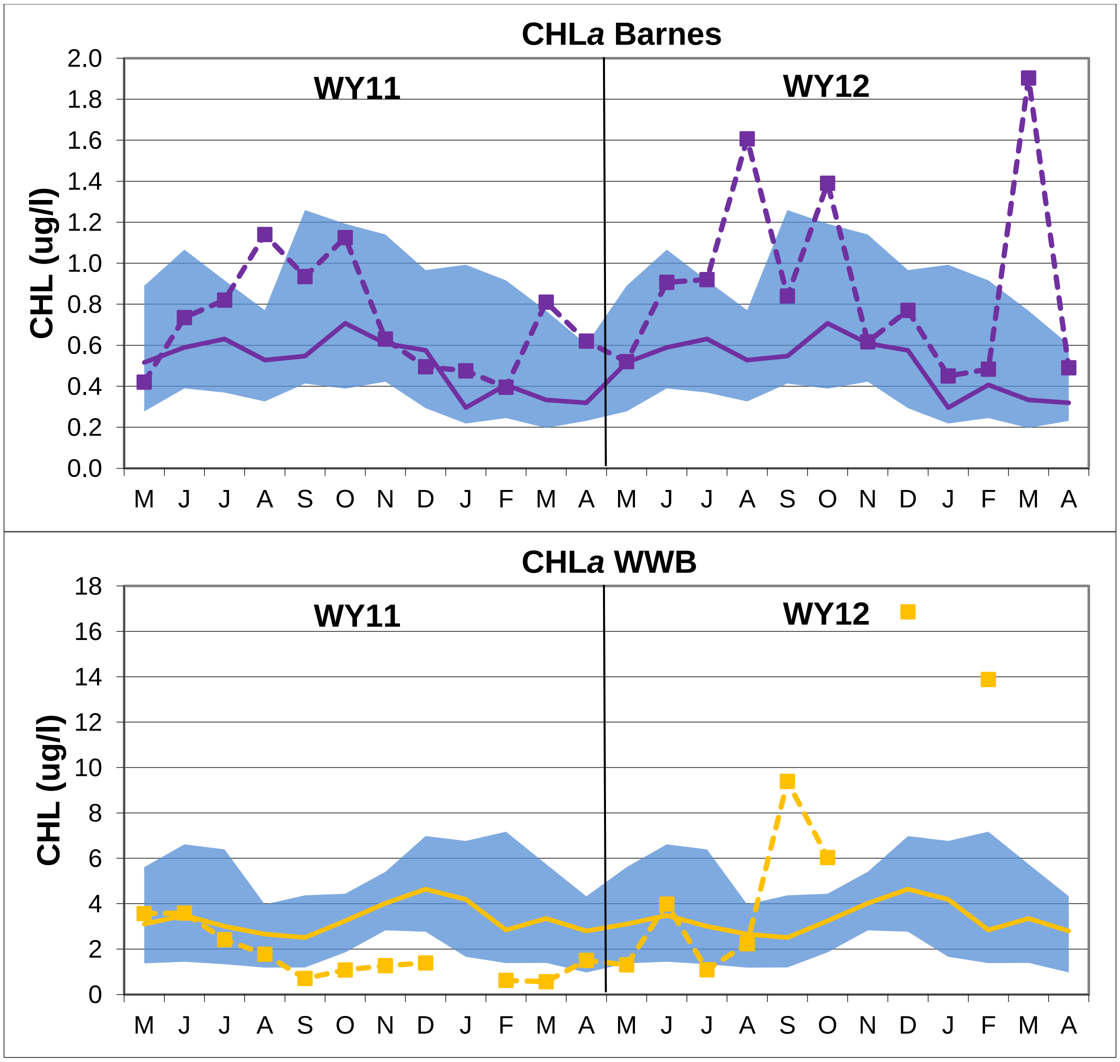

Figure 6-28. Monthly Chl*a* concentrations (in µg/L) in Barnes Sound (Barnes) and Whitewater Bay (WWB) during WY2011 and WY2012 (dashed line with solid symbols) compared to median and interquartile range of monthly means from WY1992–WY2010 (solid line and blue shading).

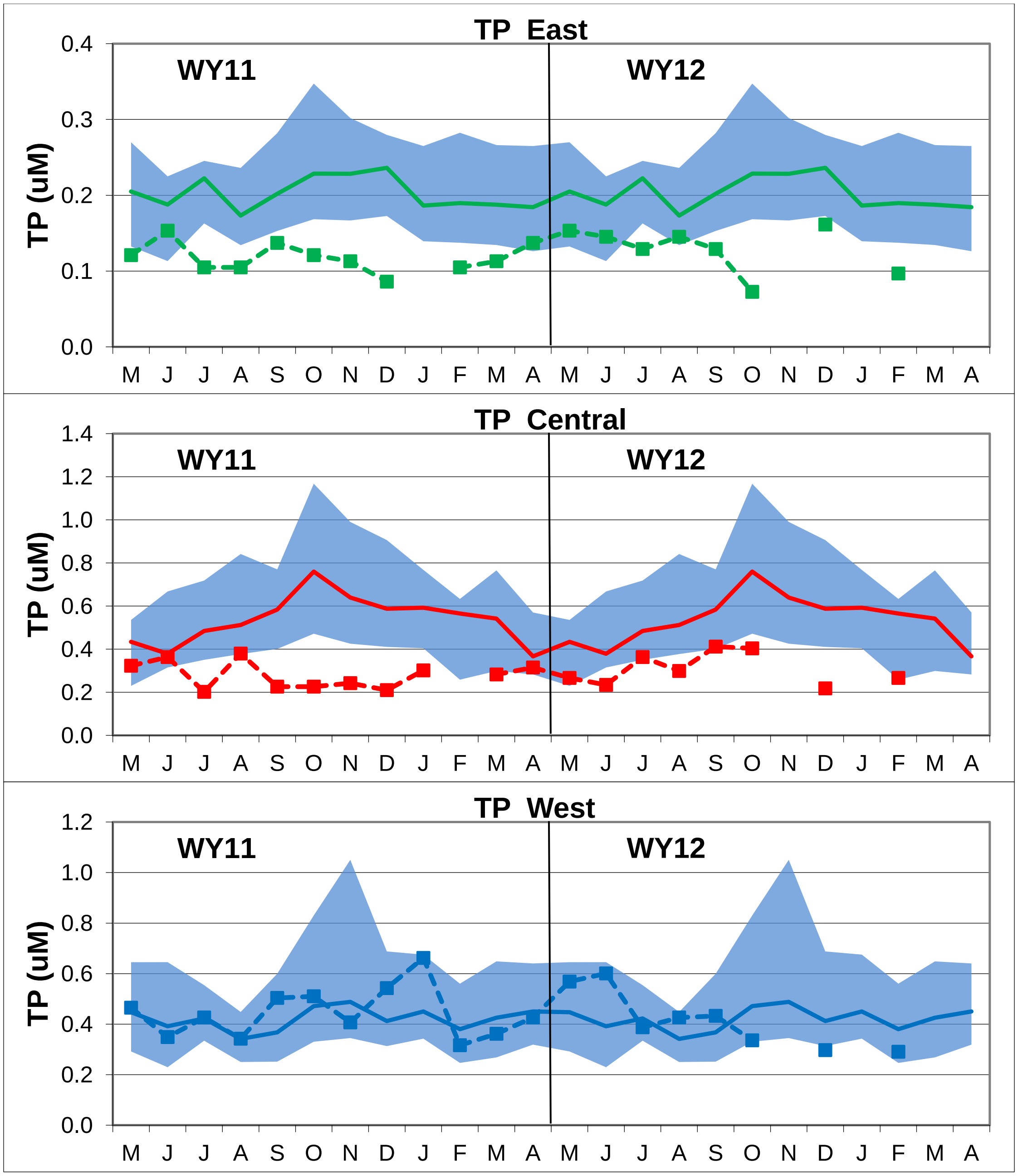

Figure 6-29. Monthly total phosphorus (TP) concentrations in micromoles per liter [μM, 1 μM = 31 μg/L = 31 parts per billion (ppb)] in the three regions of Florida Bay during WY2011 and WY2012 (dashed line with solid symbols) compared to median and interquartile range of monthly means from WY1992–WY2010 (solid line and blue shading).

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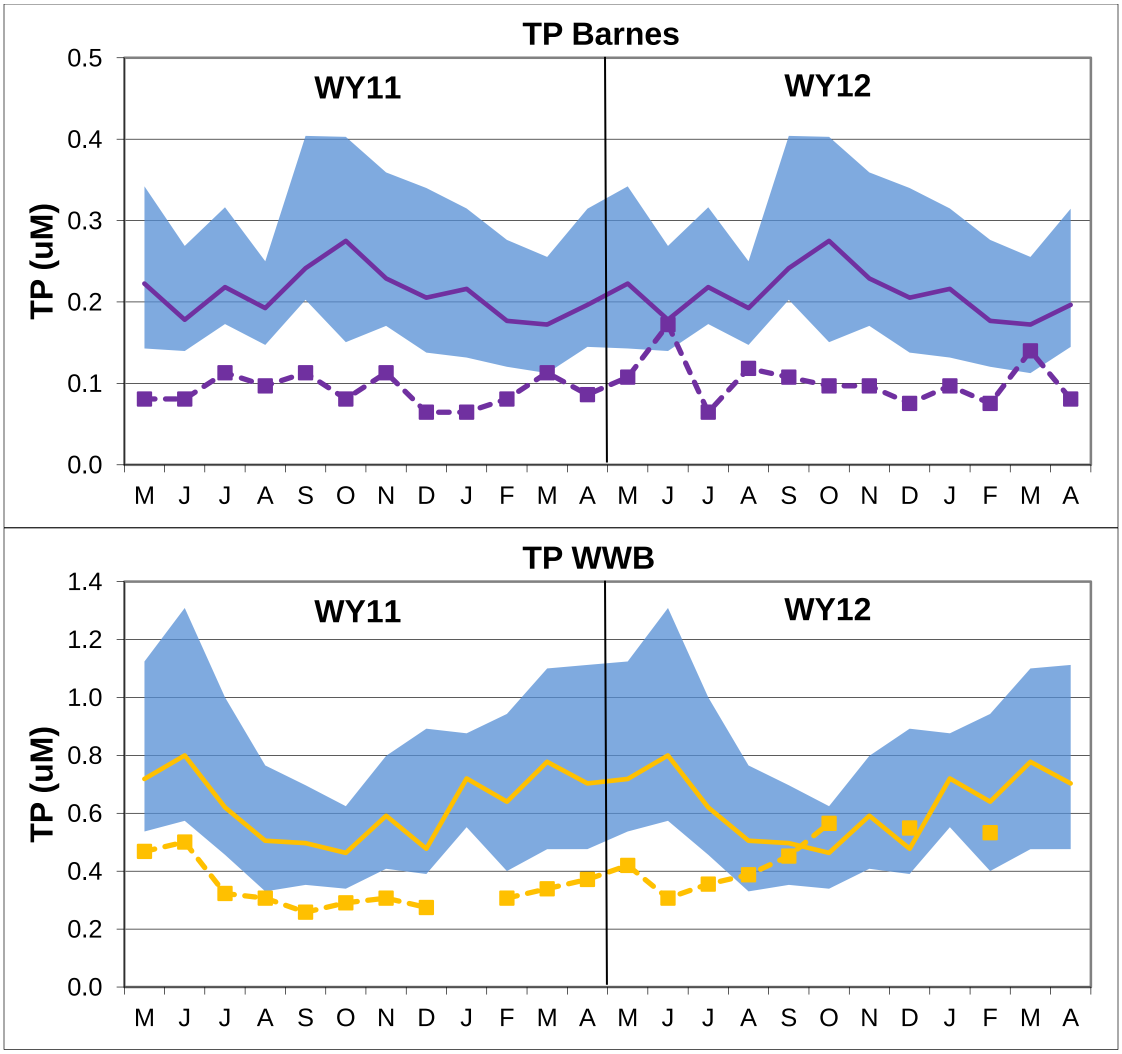

Figure 6-30. Monthly TP concentrations (in µM) in Barnes Sound and Whitewater Bay during WY2011 and WY2012 (dashed line with solid symbols) compared to median and interquartile range of monthly means from WY1992–WY2010 (solid line and blue shading).

Relevance to Water Management

In making decisions about restoration activities, it is important to understand how changes in the quantity, timing, and quality of water delivery will affect southern Everglades wetlands and the Florida Bay estuary, including nutrient and salinity regimes. The extensive research and monitoring program in Florida Bay aims to assess how increased movement of fresh water, nutrients, and organic matter from the S-332 structures and C-111 canal will affect the freshwater and mangrove wetlands of the southern Everglades.

Synoptic Patterns of Water Quality in Florida Bay

Monitoring at one place gives a profile for given variables in that location, but it is also important to know how fixed-point measurements compare to water quality across a given area. The Dataflow sampling system allows synoptic measurement of water quality parameters throughout southern Biscayne Bay and northern and central Florida Bay. The snapshot of bay conditions gives information on the influence of point source discharges on their receiving waters, permits detection of significant nonpoint sources, and enables detection of potential hypersalinity and algal bloom conditions.

Methods

Using high speed, ultra-high resolution (1 m) mapping technology (Madden and Day, 1992), the physico-chemical parameters are mapped at least quarterly to determine how upstream conditions affect the distribution of fresh water, nutrients, and chlorophyll in Florida Bay.

Results

While chlorophyll (measured by relative fluorescence units) remains muted compared to the unprecedented blooms during 2006–2008, there is an increase in the region of those blooms relative to other areas of the bay (**Figure 6-31**). Chlorophyll fluorescence in WY2012 in Blackwater Sound and Buttonwood Sound were approximately double the levels in the central bay. At the time of sampling in the late dry season, the salinity map (**Figures 6-32**) indicates there was little freshwater input, with only slight appearances in Joe Bay in the east and Seven Palm Lake in the west, and none in Taylor Slough. The system was poised to enter a hypersaline condition in the late dry season of WY2012. A previously undetected source of colored dissolved organic matter (CDOM), a measure of nutrients generally associated with fresh water, was identified in the northeast corner of Seven Palm Lake (**Figure 6-33**). The amount of CDOM will likely increase with wet season flows and work its way through the chain of lakes to the bay.

Relevance to Water Management

The significance of tracking spatial patterns of water quality parameters is that it allows relation of the sources, transformation, and fate of these parameters to both hydrology and the physical landscape. It provides for sequential mapping of parameters through time and gives multiscale information on the response of downstream waters to upstream restoration.

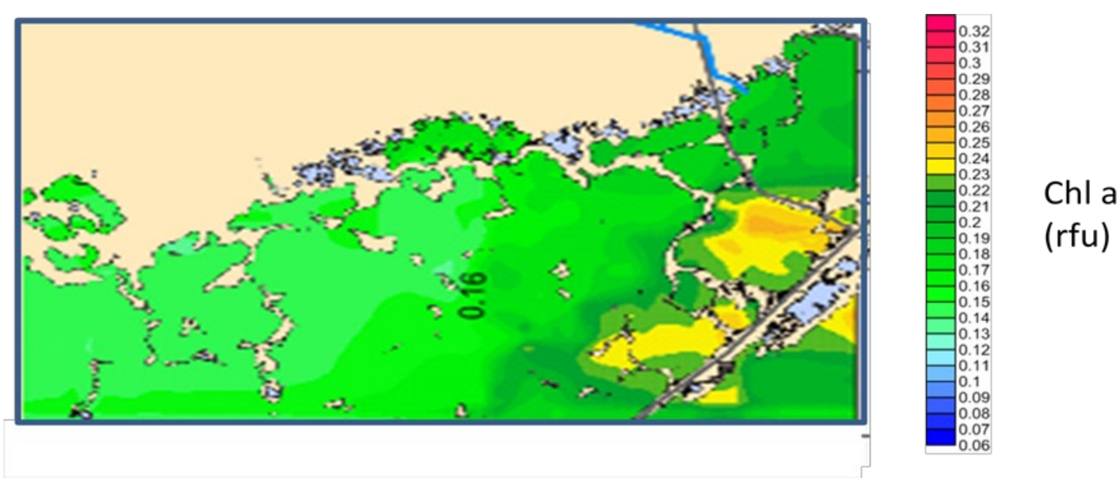

Figure 6-31. Synoptic image of Chla in Florida Bay in March 2012 showing relatively high concentrations of phytoplankton in the eastern bay, notably Buttonwood Sound and Blackwater Sound. This was the site of a large algal bloom in 2005–2008.

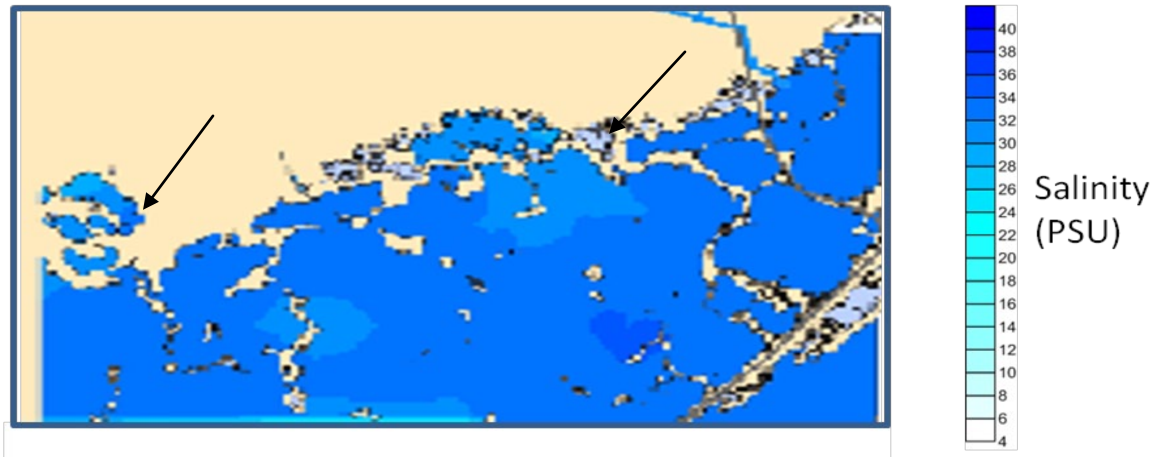

Figure 6-32. Synoptic image of salinity in Florida Bay in March 2012 showing generally marine salinities throughout (32–36 PSU), with plumes of lower salinity water discharging from Trout Creek in the east and McCormick Creek in the west (arrows).

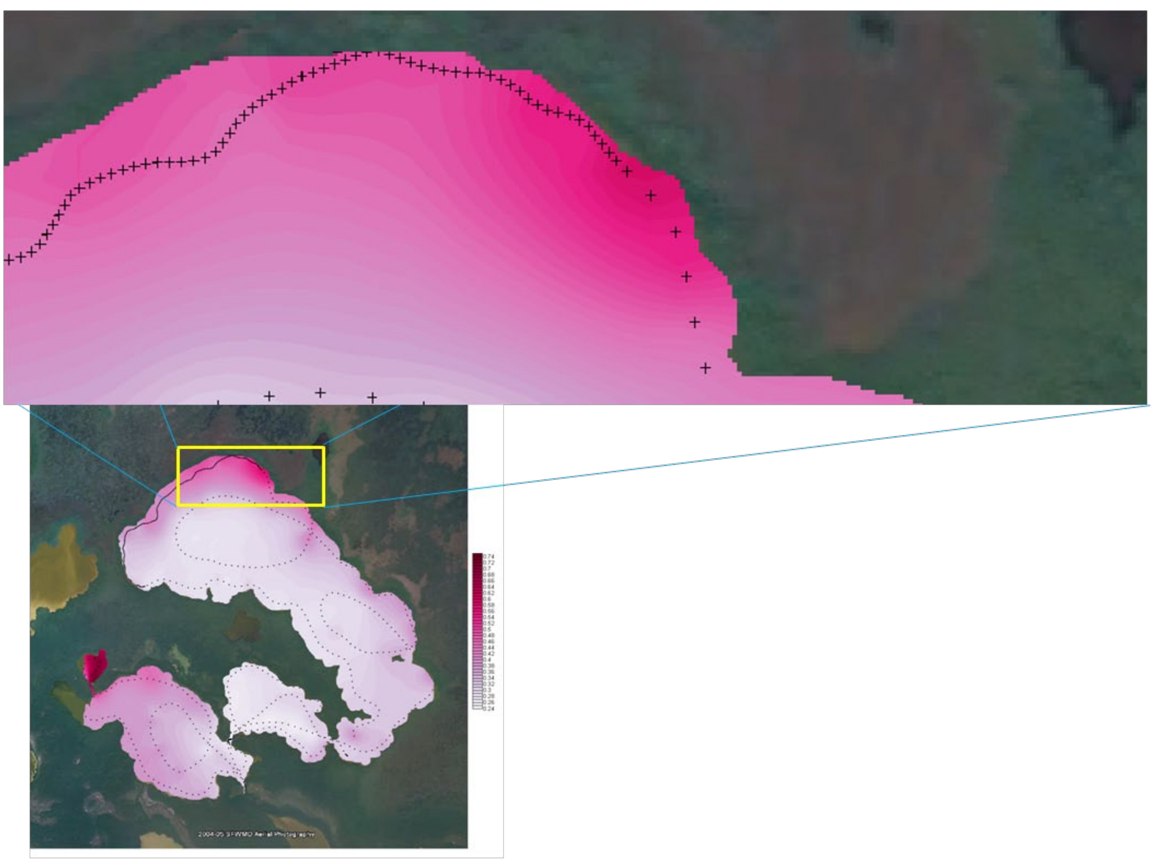

Figure 6-33. Synoptic image of colored dissolved organic matter (CDOM) in Florida Bay in June 2012 showing two "hotspots" of high CDOM infiltration to the Seven Palm Lake Basin from nonpoint sources in the mangrove ecotone.

Florida Bay Transition Zone Ecohydrology

This project measures surface water nutrient concentrations and loads discharging from transition zone creeks to Florida Bay, and the salinity in surface waters and porewaters through the transition zone, including the degraded mangrove habitat area known as the “white zone,”. Taylor Slough and the C-111 basin contribute significant amounts of water to the freshwater and estuarine portions of eastern ENP. Hydrologic restoration activities will soon change these drainages and the flow to the downstream mangrove estuaries that form the northern shore of Florida Bay. Both Taylor Slough and the C-111 basin are undergoing a major transformation in hydrology via the C-111 Spreader Canal Western Project. A three-year monitoring and assessment program for the area to be affected began in WY2010. Its goal is to help show how changes in quantity, timing, and quality of water deliveries will affect the downstream wetlands and estuary. Most of the major environmental issues associated with the southern Everglades and Florida Bay focus on three key parameters: hydroperiod, marsh water quality, and bay salinity. All are intimately tied to water delivery from Taylor Slough and the C-111 basin. This project addresses the need for continued monitoring and adaptive assessment of key water quality variables (nutrient levels, salinity regime) in the Taylor Slough and C-111 basins during and after restoration of the southern Everglades and Florida Bay.

Methods

Nutrient, hydrological, and biological parameters are being measured in an extensive network of sites throughout the C-111 Spreader Canal Western Project footprint (**Figure 6-34**), including the lower fresh marsh, the “white zone,” the extant mangrove ecotone, the buttonwood ridge, and creeks discharging into Florida Bay. Water quality has been continuously monitored at Joe Bay and Trout Creek sites in the C-111 basin and Argyle Henry, Taylor Mouth, McCormick Creek, and Alligator Creek sites in the Taylor Slough Basin. Samples are analyzed for dissolved and total carbon, nitrogen, and phosphorus nutrients.

In addition, over the last two years, a soil salinity monitoring network with 24 sites across six north-south transects has been established. At each site, surface water and porewater salinity, specific conductivity, and dissolved nutrient and carbon concentrations are monitored three or four times each year. Using soil extractions, specific conductivity and salinity patterns have been determined in early dry and wet seasons to contrast the influence of hydrologic variability on subsurface soil salinity patterns with depth and across the landscape.

Results

In McCormick Creek (MC), TN concentrations were twice as high in early dry season WY2009 and four times as high in late wet season 2009 and early dry season 2010 compared to typical concentrations found at eastern bay discharge sites. Although concentrations rarely exceeded 200 micromoles (µM) TN at MC, the Alligator Creek (AC) site had a much wider range of TN concentrations with values that exceeded 400 µM in early 2010 and early 2011 (late wet/early dry season; **Figure 6-35**). Later in the year, coincident with the end of the dry season, TN concentrations were fairly stable around 200 µM at both sites.

TP concentrations at MC were on average at or slightly above 0.5 µM, with periodic spikes at or exceeding 1 µM, except in 2011 when TP concentrations typically exceeded 1 µM (**Figure 6-35**). At Alligator Creek, TP concentrations were consistently higher than any estuarine creek station, with values in the wet season typically between 1 and 2 µM (**Figure 6-35**). Between 2010 and 2011, there were periods when TP values at AC exceeded 5 µM, higher than any values recorded for any estuarine creek site. Coincident with the end of the dry season, TP concentrations at MC stabilized around 1.0 µM whereas there was a strong seasonal trend at AC with TP concentrations averaging approximately 4 µM in June and July. TP concentrations decreased later in the wet season of 2011 at the AC site.

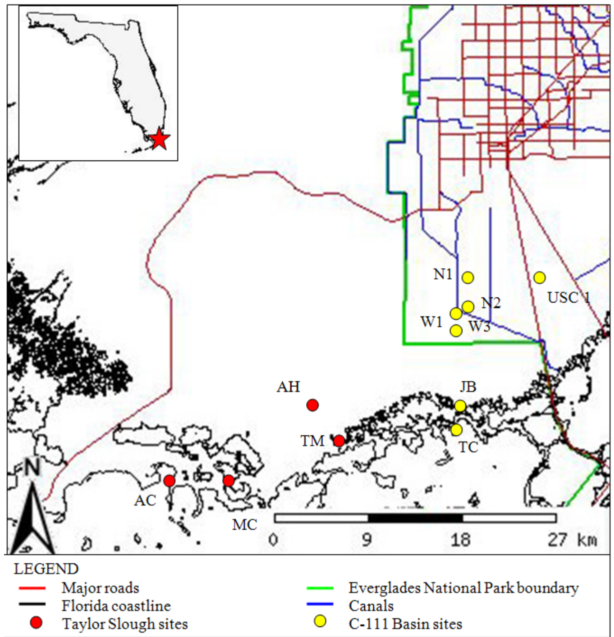

Figure 6-34. Monitoring sites along Taylor Slough and the C-111 basin.

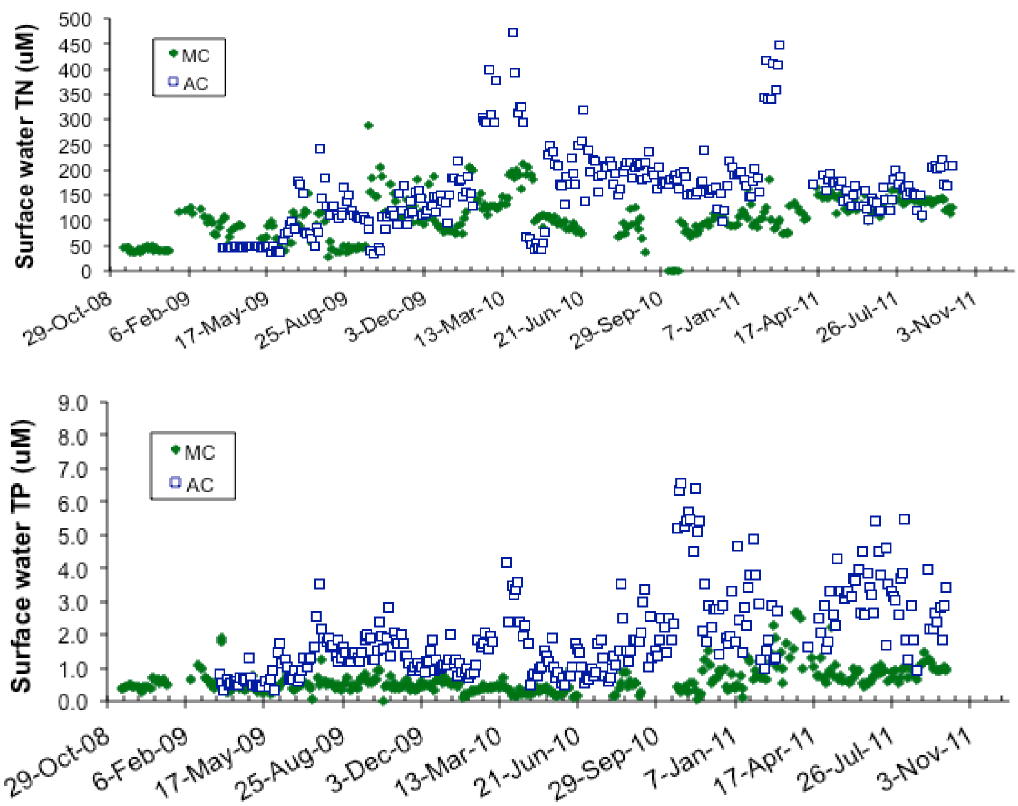

Figure 6-35. Total nitrogen (TN, upper graph, 500 µM = 7 mg/L = 7,000 ppb) and total phosphorus (TP, lower graph, 9 µM = 0.279 mg/L = 279 ppb) in surface water discharge at McCormick Creek (MC) in central Taylor Slough and Alligator Creek (AC) in western Taylor Slough, downstream of a series of highly productive lakes.

Landscape patterns in soil solution specific conductivity for early dry season WY2012, demonstrate the influence of Taylor Slough and C-111 basin water management on salinity patterns at the surface and at 15 centimeter (cm) soil depth. Specific conductivity patterns suggest greater upstream freshwater influence in ecotonal wetlands south of the C-111 basin. In the early wet season, an increased hydrologic head appears to contribute to decreased specific conductivity values in ecotonal wetlands south of the Taylor Slough watershed that remain higher than in soils of wetlands south of C-111 (**Figure 6-36**).

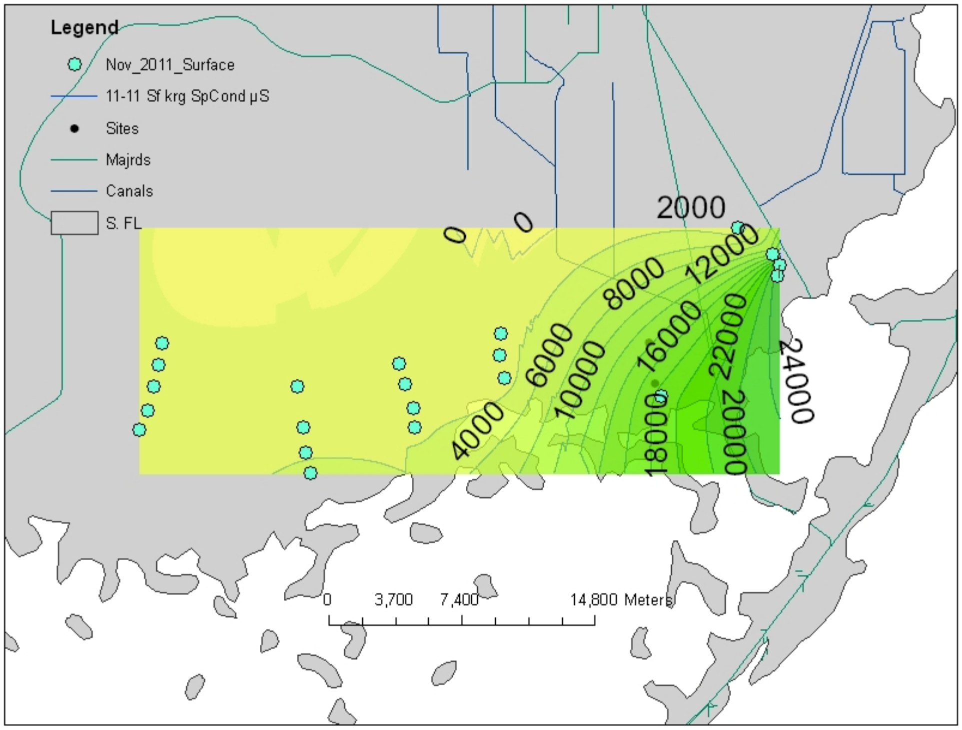

Figure 6-36. Distribution of surface conductivity (in micro-Seimens or µS) in the southern Everglades in November 2011.

Relevance to Water Management

Monitoring and research support the restoration activities in the southern Everglades in Taylor Slough and the C-111 basin. Analysis of these data permits evaluation and refinement of performance measures and restoration targets and the development and verification of simulation models. Project goals and results are being assessed by developing baseline data for sites toward the west and downstream of the region where additional water is expected to flow, as well as more easterly areas where decreases in flow may occur. The information generated by this project provides data that measures the incremental effects and effectiveness of operational changes and restoration actions in the southern Everglades.

Central Lakes Region Sediment-Water Nutrient Fluxes

The nutrient dynamics of the western boundary of Taylor Slough, particularly the lakes region from Seven Palm Lake to West Lake, is emerging as a critical area for evaluation of the C-111 Spreader Canal Western Project. Wet season and dry season measurement of nutrient uptake and release from these lake bottoms has been assessed as part of the baseline measurement for the C-111 project and will continue to assess its impact on these downstream waters.

Methods

Intact sediment cores and bottom water were collected from transition lake bottoms (Seven Palm Lake, Middle Lake or Monroe Lake, Terrapin Bay, West Lake, Long Lake, and Garfield Bight) and incubated in a temperature-controlled incubator in the laboratory under dark and light conditions for approximately four hours each in May 2011. At seven time points, three in the dark, one at the dark/light transition, and three in the light, samples were collected for nutrient and gas samples. Sediment–water exchange rates were calculated from the slope of the change of the chemical constituent concentrations in the overlying water.

Results

The effects of benthic microalgae were evident throughout these northern Florida Bay–southern Everglades ecosystems, with high rates of photosynthesis and strong retention of nitrogen under illuminated conditions. Losses of fixed nitrogen as N_2-N were relatively low, likely reflecting the dominance of autotrophic nitrogen uptake and the relative inefficiency of coupled nitrification–denitrification in sulfidic sediments with high rates of oxygen uptake. Net fluxes of both TP and TN were highly variable, with positive and negative fluxes. Results during WY2012 (May 2011) were similar to the wet season study conducted in July 2010 and indicate sediment recycling of inorganic nitrogen results in relatively large effluxes of ammonium (**Figure 6-37**). In most cases denitrification was relatively limited. Results from these two studies of ENP saline lakes are similar to benthic flux results from nine sites in Florida Bay in 1999 (**Figure 6-37**). This implies that finding high nutrient concentrations and chlorophyll *a* in several ENP lakes may be more related to the lakes' long water residence time and possibly to other nutrient sources such as groundwater.

Relevance to Water Management

The lakes study program aims to quantify baseline (pre-restoration) and post-restoration rates of benthic nutrient and metabolic gas fluxes from sediments in the transition zone. It is important to understand how water column and sediment processes will be affected by freshwater input to the transition zone since some of these processes have the potential to release nutrients to overlying waters that may cause algal blooms when transported downstream to the bay.

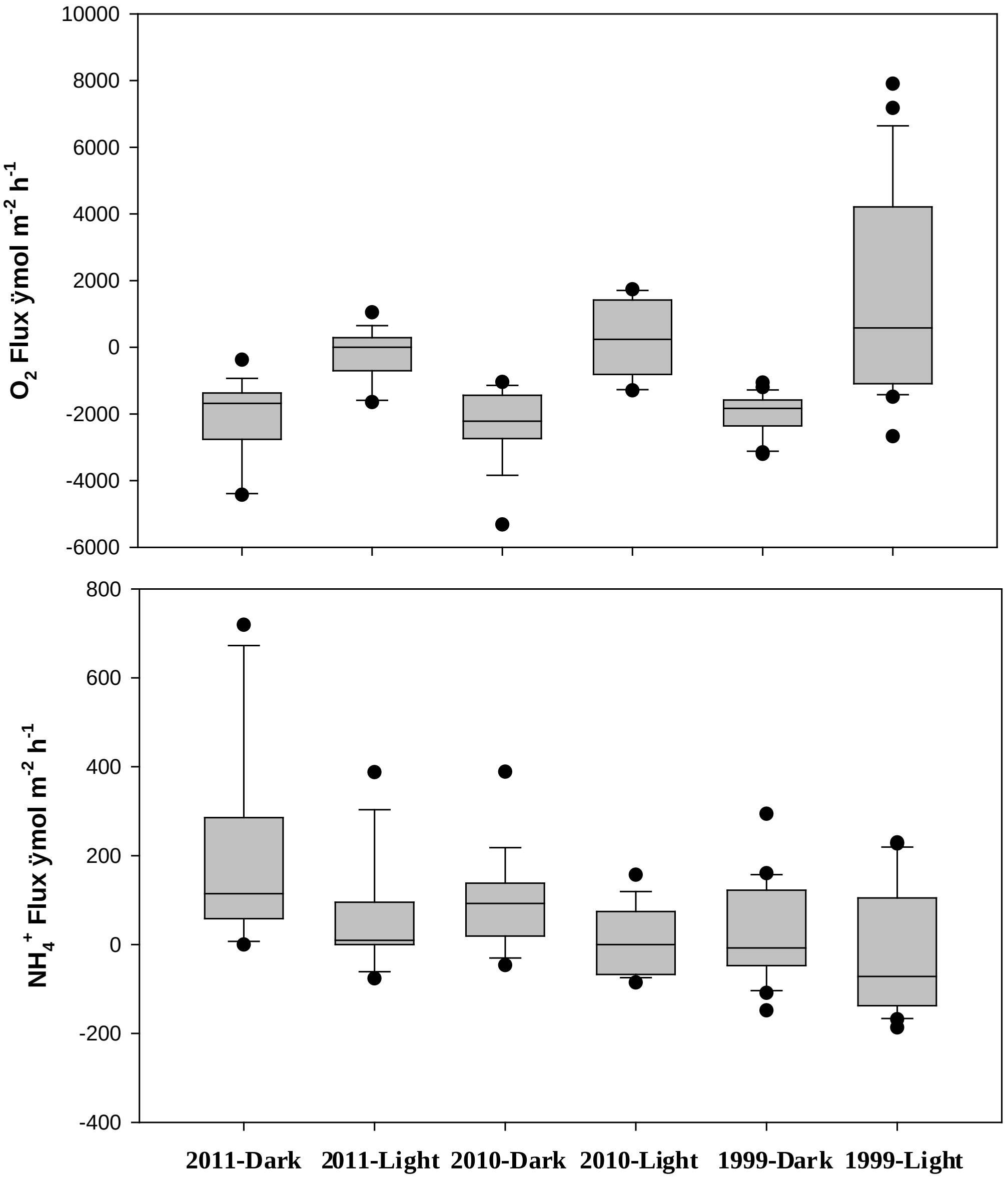

Figure 6-37. Box plots of fluxes from sediment cores collected in May 2011 and July 2010, as well as estuarine data from nine sites in Florida Bay (Kemp and Cornwell, 2001). The horizontal line in the box represents the median value of the flux rates; the 25% and 75% range for the data are represented by the boxes and the bars represent the 0–25 and 75–100 representation of the data. Dots are considered outliers.

LANDSCAPE

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Carlos Coronado Molina, Ted Schall[4], Colin J. Saunders,
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Tree island habitat change analysis over the past century was conducted using remote sensing. In addition, satellite imagery sources for mapping vegetation in the Everglades are compared. Finally, initial results from pre-project sampling for the Decomp Physical Model are reported.

AREAL LOSSES AND GAINS IN TREE ISLAND HABITAT IN SHARK RIVER SLOUGH, EVERGLADES NATIONAL PARK – INFERENCES FROM 1952–2004 IMAGERY ANALYSES

Though tree islands account for less than 10 percent of the Everglades landscape, they provide habitat necessary to maintain floral and faunal biodiversity while significantly affecting hydrological and biogeochemical processes of the ecosystem (Sah, 2004; Troxler-Gann and Childers, 2006; Givnish, 2008; Wetzel et al., 2008). Over the twentieth century, the number and total area of tree islands have been roughly halved (Patterson and Finck, 1999; Brandt et al., 2000). A goal of CERP is restoring the pre-drainage Everglades ridge–slough–tree island landscape. Achieving this goal requires quantifying how management and naturally driven forces (e.g., hydrologic, disturbance, internal ecological feedbacks) impact tree island structure and functioning (e.g., primary production, plant community diversity, soil accretion).

Extreme hydrologic patterns have degraded tree island forest composition (Sklar and van der Valk, 2002; Rutchey et al., 2008; Wetzel et al., 2008), but most data do not extend beyond the last 20 years (Wetzel et al., 2008). Previous mapping efforts (Sklar and van der Valk, 2002) have found tree island degradation or loss on 90 percent and 60 percent of WCA-2A and WCA-3A, respectively since the 1940s. This loss is thought to be due to a sequence of extensive drying and soil oxidation, followed by rapid and prolonged flooding (Wu et al., 2002). This hydrologic sequence did not occur in the ENP. While drying occurred in the Park, structural modifications along the eastern boundary did not create the same flooding pattern seen in the rest of the Everglades. Therefore, tree islands in the ENP were considered relatively healthy and could be used as an indication of island expansion as ridges with short hydroperiods become tree islands. To test this hypothesis, a new mapping program for Shark River Slough began in earnest in 2011.

Methods

Tree islands were mapped within Shark River Slough through stereoscopic analyses of historic aerial photography from 1952, 1960/64, 1973, 1984, 1995, and 2004 (**Figure 6-38**). The aerial photography consisted of panchromatic and false color infrared film products from the records of the United States Department of Agriculture, the United States Geological Survey, and the National Archives. All historic film products were subsequently digitized and georeferenced to provide a three-dimensional view of the Everglades landscape over time.

[3] United States Geological Survey
[4] United States Army Corps of Engineers, Jacksonville, FL
[5] Atkins North America, Miami, FL

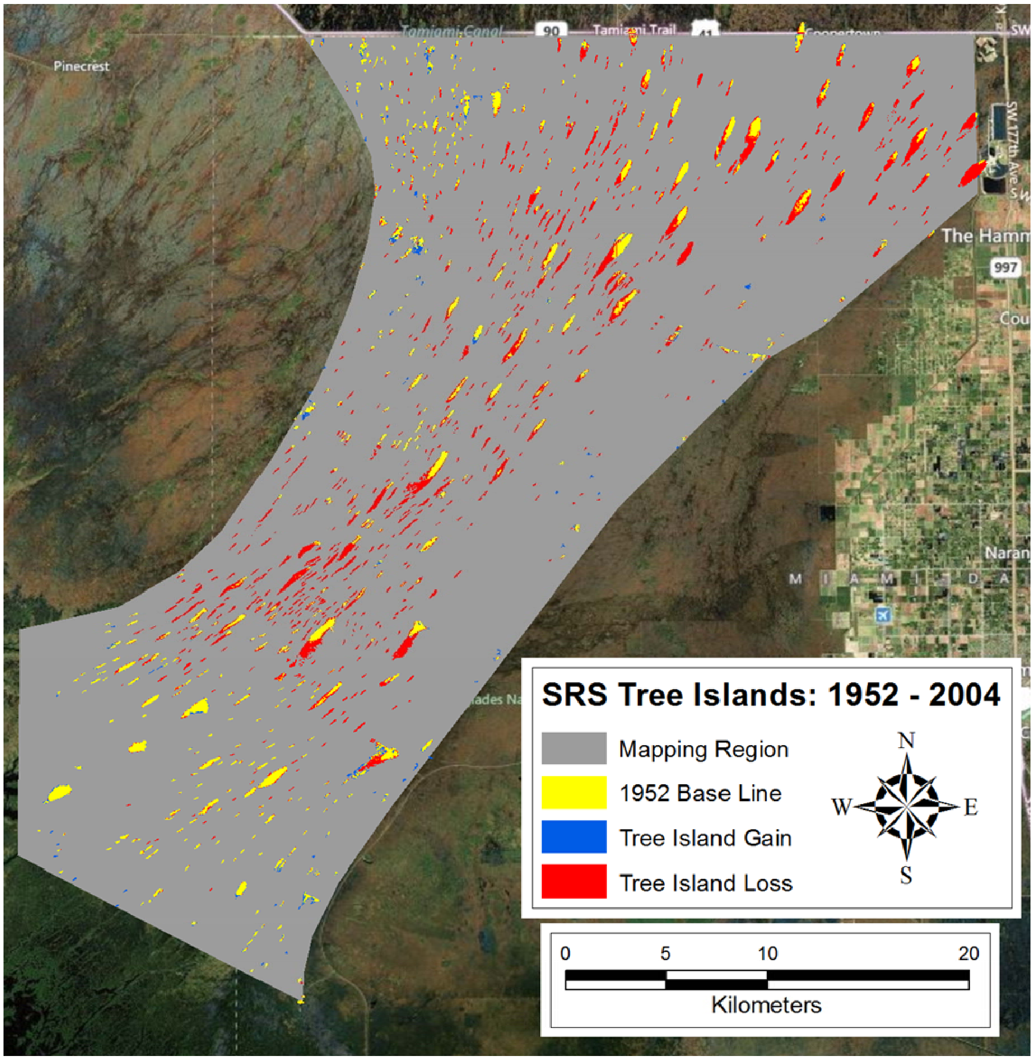

Figure 6-38. Tree islands within Shark River Slough (SRS) for 1952–2004. The gray region indicates the extent of tree island mapping and the locations for which no tree islands were recorded, yellow regions indicate islands present in 1952 and remaining in 2004, blue regions indicate an expansion of tree island communities, and red regions indicate lost tree island habitat.

Tree islands were defined and mapped from the imagery according to the following specifications:

1. A contiguous area demonstrating 10 percent or greater areal coverage of trees and shrubs
2. The area of trees and shrubs must demonstrate a tapered and compact shape generally indicating the direction of hydrologic flow within the marsh
3. The area of trees and shrubs must not be composed primarily of invasive *Melaleuca* spp.
4. The total area of trees and shrubs must be 1 hectare (ha) or greater

These criteria were specifically designed for mapping tree islands, including the head and tail portions of the islands, and were intended to exclude other non-island woody landscape features such as the expansive regions of willow and pond-apple (*Anonna glabra*) adjacent to Tamiami Trail and the tidal creek forest communities at the southernmost end of Shark River Slough.

Results

Tree island habitat, as defined by the mapping criteria, has substantially declined in Shark River Slough and the immediately adjacent wet prairie habitats since the 1950s (**Figures 6-38** and **6-39**). The total number of tree islands greater than 1 ha declined from 961 in 1952 to 496 in 2004 (48.4%). The areal coverage of tree island habitat greater than 1 ha has declined from 5,036.6 ha in 1952 to 2,291.3 ha in 2004 (54.5%). The largest single decadal decline occurred from 1960/64 to 1973. During this period, 1,095.5 ha (23.3%) of the 1960s era tree island habitat was lost. Each era demonstrates some regional increases in tree island habitat. On average 162.9 ha (3.2%) of the 1952 total area of island habitat was added per decade. However, modest regional increases did not outpace declining habitat elsewhere in Shark River Slough. In addition, increases in tree island habitat appear to be primarily related to the expansion of willow and cypress (*Taxodium* spp.) while declining habitat appears to be primarily associated with Bayhead communities (Schall, personal observation).

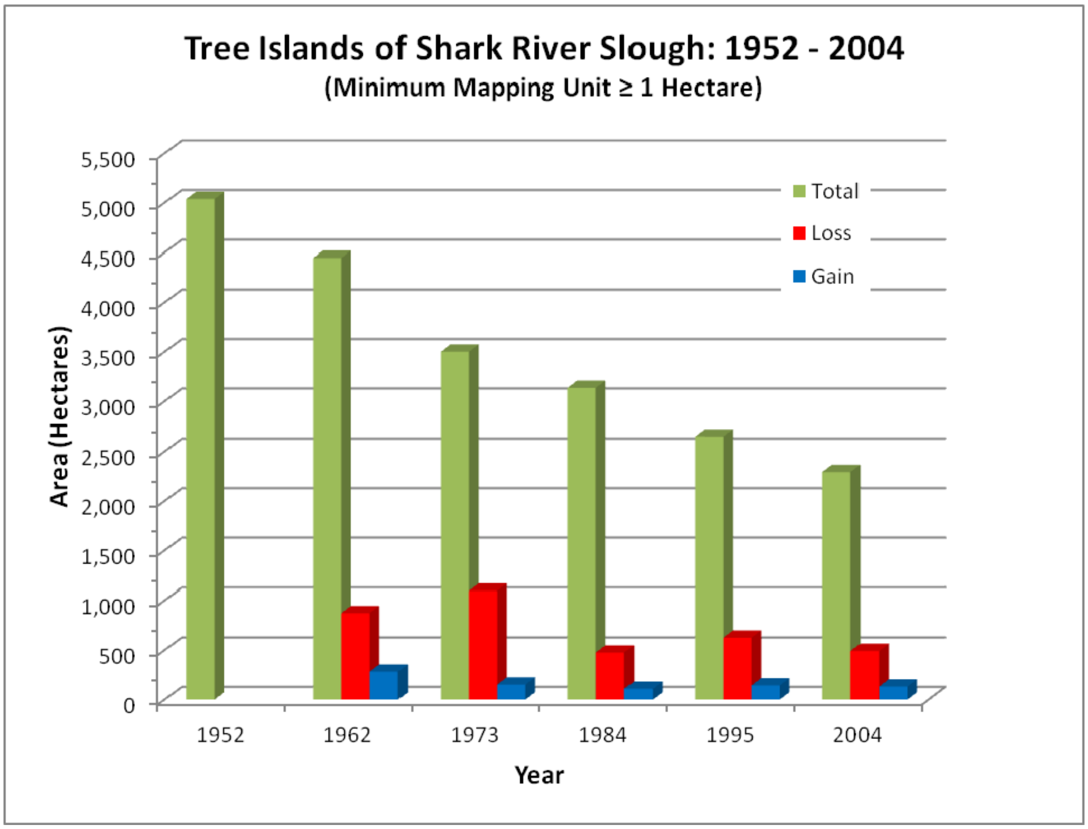

Figure 6-39. The cumulative area (green), decline (red), and expansion (blue) of tree island habitat in each mapping year from 1952 through 2004. The 1952 mapping was used as the baseline condition for the analysis. The 1962 data was compiled from aerial photography acquired in 1960 and 1964.

Discussion and Significance to Water Management

Similar previous aerial photo mapping efforts demonstrated an expansion of woody vegetation within Shark River Slough. To better understand the differences between those previous studies and this mapping effort, maps provided by each of the previous studies were georeferenced and directly compared to the three-dimensional imagery used in this study.

Johnson (1958) provided 1940 and 1952 era maps for three sample locations within Shark River Slough. Within those areas he mapped regions of woody vegetation described as "heavy" and "lighter" growth utilizing monoscopic photographic tracing methods. Johnson's maps for the 1952 era did not compare favorably to the digitally enhanced three-dimensional imagery of the same period. The stereoscopic image analyses of the 1952 Johnson maps demonstrated that his regions of "heavy" woody vegetation corresponded fairly well with the boundaries of tall sawgrass ridge features and his "lighter" woody features could best be characterized as graminoid features that appeared be primarily lower stature sawgrass. The "lighter" woody features demonstrated little evidence of the presence of trees and shrubs and the "heavy" woody class, while containing areas of dense trees and shrubs such as tree islands, did not accurately demonstrate the extent of such features. Moreover, the largest single area of tree and shrub expansion presented by Johnson included an area of willow and pond apple along the south side of Tamiami Trail and extending southward into the Park. This specific feature was intentionally left out of this study because it did not satisfy the tapered and compact shape characteristics of a tree island.

Kolipinski and Higer (1969) used an analog stereoscopic mapping methodology to create three-class vegetation maps for 12 sample sites comprising approximately 5 percent of Shark River Slough. Unfortunately, the literature only provided maps for two of the sites. The maps were designated as Section 22, Township 57, Range 34 (S22-T57-R34) and S11-T56-R36 of the Florida Public Land Survey System and depicted a "tree and shrub" community for years 1940, 1952, and 1964. Modern stereoscopic image analyses of the 1952 and 1964 Kolipinski and Higer maps demonstrated that these maps were reasonably accurate in terms of their tree and shrub community depiction. However, gains in woody vegetation within S22-T57-R34 were related to the expansion of what the authors described as the "river-bank" forest community on the embankments of the tidal creeks of Shark River. These specific forest communities, like the expansive area of willow and pond-apple along Tamiami Trail, were not mapped in this study because they did not qualify as tree islands. Kolipinski and Higer also documented an average 3 percent gain in tree and shrub area per decade for their sample locations in the mid to upper portions of Shark River Slough. Their findings are consistent with the 3.2 percent average decadal increase in tree island communities presented in this study with the exception that the complete survey undertaken in this study established that regionally specific increases in tree island habitat were outpaced by losses in other portions of Shark River Slough.

Nonlinear regression modeling to quantify trends in tree island habitat since 1950 in this study were significant and had r^2 values greater than 0.98 for both island numbers and acreage, suggesting that further declines in tree islands within Shark River Slough can be expected. By 2020, the model predicts an additional decline of 19 percent to a new population of approximately 400 tree islands greater than 1 ha. In the same period, the cumulative area of tree island habitat is expected to decline an additional 21 percent to approximately 1,800 ha.

Some evidence to the cause of the decline and to the succession of tree island habitats during this period is contained within the historic aerial photography. There is evidence that this loss of tree islands is due to fires and the inability of islands in the Park to maintain the high humidity firebreaks that have been observed in WCA-3A (Sklar, personal observation). The historic photography also contains information regarding the quality of the tree island habitat, for example canopy height, tree density, and perhaps island type. Documentation of this additional information is necessary to provide a better understanding of how and why tree islands have changed over the last 50 years and what might be in store for their future.

EFFECTIVENESS OF GREATER EVERGLADES VEGETATION CLASSIFICATION USING WORLDVIEW 2 SATELLITE DATA

The authors evaluated the use of remote sensing data to detect and map Everglades wetland plant communities at different scales, and compared map products delineated and resampled at various scales with the intent to quantify and describe the quantitative and qualitative differences between such products.

Methods

Data from Digital Globe's WorldView 2 (WV2) sensor with a spatial resolution of 2 m and Landsat's Thematic and Enhanced Thematic Mapper sensors with a spatial resolution of 30 m were compared for their ability to detect plant community classes. The data were used to map areas immediately north and south of the Tamiami Trail Bridge (TTB) and an area in the western part of WCA-3A (WE3A). To evaluate the suitability of remote sensing to detect plant communities in these landscapes, the researchers (1) established plant community classification schemata based on field surveys, (2) acquired satellite data and performed atmospheric corrections, (3) evaluated different classifiers, and (4) classified images using the classifier with the highest model-based accuracy. Atmospherically corrected, multispectral biseasonal images were used for both data sets, and in the case of WV2 data, one local texture variable (variance for a 3x3 kernel) was included. The performance of single tree (cTree) versus multiple tree (random forest) recursive partitioning algorithms was tested for classification. The adequacy of each data set to map wetland plant communities was evaluated utilizing two metrics: (1) model-based accuracy estimates of the classifier, and (2) design-based post-classification accuracy estimates based on stratified random samples of mapped community classes.

To investigate the scalability of plant community maps generated with remote sensing methods, class diversity and class proportionality of maps were compared in two ways: (1) when aggregated with grid-based versus morphological spatial aggregation procedures, and (2) when classified at lower spatial resolutions. For the grid-based method, the 2 m x 2 m resolution WV2 map was aggregated to the 30 m x 30 m grid of the Landsat image and to the 50 m x 50 m grid utilized in visual interpretation of aerial photography by CERP. For the morphological spatial aggregation method, a morphological aggregation algorithm was used that aggregated contiguous pixels in the same class based on the minimum mapping unit, rather than aggregating by a grid with an arbitrary origin. Thus, in the morphological aggregation, pixels could be aggregated in non-square shapes.

Results

For plant community class detection, WV2 satellite images provide data with spatial, spectral, and radiometric characteristics suitable for classifying Everglades wetland plant communities (**Figure 6-40A**). While Landsat satellite imagery preserved the general landscape morphology seen in the WV2 maps, they differed in detail. The Landsat maps lacked the degree of patchiness and community interspersion present in the WV2 images; individual patches had different sizes and shapes; and some community classes were lost (**Figure 6-40B**). The best model for plant community classification with WV2 imagery was one using the random forest algorithm and biseasonal spectral and textural data. The best model for the Landsat images was similar although no textural data were used for these images. In general, accuracy was highest when pixels were classified at the community class thematic level and then aggregated to the structural level versus classified at the community structure level.

The study of scaling effects showed overall accuracy increased with scaling to lower thematic and spatial resolution. Classification at a lower spatial resolution caused loss of some community classes. In both TTB and WE3A, classifying vegetation at different scales changed the presence and abundance of community classes (**Figure 6-41**). When classifying at the community class level, decreasing the spatial resolution decreased class diversity; the same trend was present but not as marked at the structural level. In both TTB and WE3A, aggregating WV2 pixels from 20 to 2500 m^2 using the morphological aggregation method lost fine-scale community class details and degree of community interspersion, but overall community class shapes were preserved. The grid-based aggregation preserved the location and spatial distribution of large landscape classes, but the landscape shapes were pixilated and some classes were lost entirely (**Figure 6-41**). Loss of classes was independent of abundance but was related to maximum patch size of a class.

Applications

This study provides a methodology to monitor landscape changes in response to management decisions using WV2 satellite data. The maps resulting from these data preserved the shapes of landscape features at a high precision even when the minimum mapping unit was increased if the morphological aggregation algorithms rather than grid-based methods were used. Using these data, it should be possible to monitor changes in the shapes of these features. Additionally, the ability to map at a high resolution and then aggregate to lower resolutions provides a way to quantify the effects of heterogeneous communities on the spectral signatures of coarser resolution satellite data, such as that derived from Landsat imagery. Thus, the WV2 imagery provides a way to calibrate and interpret the more widely available Landsat data.

Figure 6-40. Vegetation classification result for WE3A classified at the community class value (A) from WorldView 2 (WV2) aggregated at 20 m^2 minimum mapping unit (MMU) and (B) from Landsat at 900 m^2 MMU. Map classes are open water (OW), floating periphyton (Pf), broad-leaved *Blechnum serrulatum* (BLbs), broad-leaved mix (BLmix), broad-leaved *Peltandra virginica* (BLpv), floating-leaved *Nymphaea odorata* (FLno), floating-leaved *Utricularia* (FLu), tall graminoid *Cladium jamaicense* (GTcj), tall (GTcjT), tall graminoid *Typha* (GTt), bayhead shrub (SB), shrub *Salix caroliniana* (Ssc), and bayhead tree (TB).

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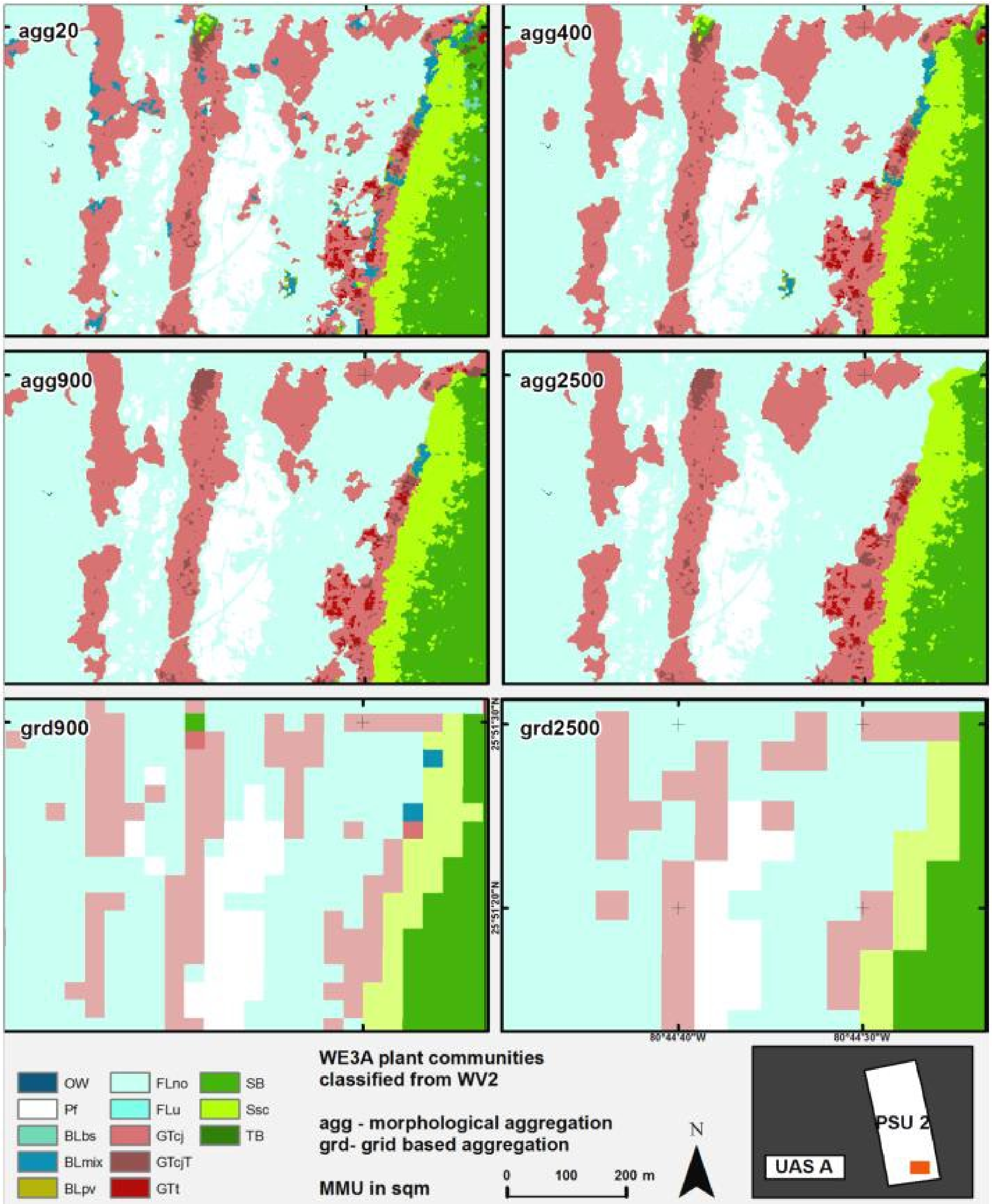

Figure 6-41. Comparison of morphological aggregation (agg) method at 20, 400, 900 and 2,500 m^2 and grid-based aggregation (agg) at 900 m^2 (MMU equivalent to Landsat pixels) and 2,500 m^2 (MMU equivalent to CERP vegetation mapping grids) for a subset of the area in western WCA-3A. See **Figure 6-40** for class definitions.

BASELINE CONDITIONS FOR THE DECOMP PHYSICAL MODEL

Over the last century, hydrologic segmentation of the Everglades via canal and levee construction has lead to the degradation of prominent features of the landscape. Historically characterized by linear sawgrass ridges and deep sloughs oriented parallel to flow and typically separated by more than 30 cm of microtopographic relief (McVoy et al., 2011), this patterning is completely lost in areas of the modern system where flow is virtually absent, and overdrainage or impoundment has occurred. Further, even in the apparent "pristine" areas, historical accounts indicate that the current microtopography is a fraction of what it was, suggesting such areas continue to degrade (McVoy et al., 2011; Watts et al., 2011). The loss of microtopography and the filling in of the long, deepwater sloughs equates to a reduction in aquatic productivity and ecological connectivity, key ecosystem functions that sustain consumer populations (Hoffman et al., 1994; Green et al., 2006).

Restoring sheetflow is critical to rebuilding the patterned, corrugated landscape of the Everglades. Modeling studies indicate that water velocities greater than 2 centimeters per second (cm/s), several-fold higher than measured in the current system, may be needed to sufficiently entrain and redistribute sediment to build landscape patterning and topography (Larsen et al., 2011). However, these important advances in understanding the mechanisms of landscape formation and degradation have been made using small-scale experiments and large-scale modeling. Scientific and engineering uncertainties remain over how rapidly the ridge and slough landscape will respond to restored sheetflow. In addition, even with restored sheetflow and levee removal, it is unknown to what extent existing canals will hinder the restoration of the landscape. In this regard, key restoration uncertainties for decompartmentalizing the current impounded system include (1) the extent to which canals must be backfilled to ensure the restoration of sheetflow and sediment redistribution and (2) the extent to which restored sheetflow conditions may facilitate the transport of high-nutrient canal sediments to downstream areas.

DECOMP Physical Model

Located in the area between the L-67A and L-67C structures known as "the pocket" (**Figure 6-43)**, the DECOMP Physical Model (DPM) is a multiagency, multidisciplinary, landscape-scale project designed to address uncertainties associated with the effects of sheetflow and canal backfilling options on the ridge and slough landscape. The central research questions addressed by the DPM are:

1. <u>Sheetflow:</u> To what extent do entrainment, transport, and settling of sediments differ in ridge and slough habitats under high and low flow conditions? Does high flow cause changes in water chemistry and consequently changes in sediment and periphyton metabolism and organic matter decomposition?
2. <u>Canal Backfill:</u> Will canal backfill treatments act as sediment traps, reducing overland transport of sediment? Will high flows entrain nutrient-rich canal sediments and carry them into the water column downstream? To what extent are these functions altered by the various canal backfill options, including partial and full backfills?

Twenty-three specific physical and biological hypotheses are addressed by the experiment and are detailed in the DPM Science Plan (DPM Science Team, 2010).

To reproduce pre-drainage flow conditions, new structures are being built for the experiment, including 10 gated culverts on the L-67A levee, a 3,000-foot gap in the L67C levee, and three 1,000-foot canal backfill treatments in the adjacent canal (**Figure 6-43**). With a combined discharge capacity of 750 cubic feet per second (cfs), the culverts are expected to generate water velocities of 2–5 cm/s in the flow-way. The DPM utilizes a Before-After-Control-Intervention (BACI) experimental design, consisting of field monitoring of hydrologic and biological parameters under no-flow (baseline) and high-flow (impact) conditions in both impacted and non-impacted marsh and canal "control" sites. Due to water quality and flooding constraints, the operational window of the S-152 is limited to November–December. Construction is expected to be completed in 2012.

Reporting Objectives

In the BACI experimental design, it is necessary to explain the baseline variability in the response variables, so that impact (high-flow) effects can be distinguished from existing sources of variability in the data (e.g., weather or fire events, local variation among habitats and sites). All the data reported here were collected under the baseline, low-flow conditions. This section highlights sources of temporal and spatial variability and provides a preliminary landscape sediment budget as a means to synthesize the different data types. Only a subset of measured variables is reported here: flow velocity and direction, water chemistry, and sediment transport and accumulation rates. Though these parameters do not provide a complete picture, they represent the core information needed to characterize the hydrology, biogeochemical properties, and mass budgets of the study site, and are key parameters expected to change under the high-flow impact. Further, they provide the necessary context for understanding the larger, inclusive array of physical and biological parameters, to be included in subsequent reporting.

Methods

Flow velocity and direction were measured at fixed depths in the water column using 10 megahertz (MHz) down-looking Acoustic Doppler Velocimeters (ADVs) with a resolution of 0.01 cm/s and an accuracy of 1 percent of measured velocity (SonTek, 2001). ADVs measured water velocities every 30 minutes, which were averaged to produce daily values (Lightbody and Nepf, 2006). Vegetation community structure is known to alter water flow in Everglades wetlands (Larsen et al., 2009); therefore, at select sites, vegetation structural components were measured including biovolume from surveys, harvests, and photographic analyses (Lightbody and Nepf, 2006).

Water column samples were collected monthly during October 2010–January 2011 and July 2011–January 2012. Samples were collected mid-water column using a peristaltic pump, preserved, and analyzed following standard District protocols. To obtain more detailed information on particle chemistry, water column total particulate phosphorus (TPP) was obtained from water samples collected in November 2010 and November 2011. Samples collected for water column suspended sediments were passed through 500 micrometer (µm) Nitex mesh prior to being stored on ice and brought to the laboratory for processing. Immediately upon return to the laboratory, samples were filtered though a 0.2 µm Pall membrane filter. The filters were digested and analyzed for TPP.

Sediment traps were used to measure sediment transport in marsh sites and the deposition of sediment in the canal treatments. To measure horizontal transport, sediment traps were constructed with adaptations from a design used to quantify sediment exchange in estuarine systems (Phillips et al., 2000). These traps represent a novel method for measuring sediment transport in Everglades wetlands. Six traps are deployed across the DPM, including one each in paired ridge and slough plots at three marsh sites. Traps were oriented parallel to flow and deployed for three weeks during the S-152 operational window (November–December) and six weeks during the non-operational period (January–May). Loading rates were estimated as grams per frontal area per time, where frontal area was measured from the diameter of the inlet and outlet tubes (6.4 mm). Loading rates per frontal area were converted to loading per ground area based on the measured water depths.

To capture vertical sediment deposition in the canals, three sets of vertical sediment traps per treatment were suspended 1 m above the sediment-water interface. Traps consist of three vertically oriented tubes with a length to width ratio of 8:1 (Kerfoot et al., 2004) and kept vertical using floats. Canal trap deployments are synchronized with marsh trap deployments. Samples collected from all sediment traps were stored cold and transported to the lab for processing. Samples were passed through a 1 millimeter (mm) mesh sieve to separate large (>1 mm) and small (<1 mm) sediments. Since median sediment particle size is less than 100 µm (Noe et al., 2007), only the small particles are presented in this report.

Results and Discussion

Hydrology

While water velocities were generally higher in sloughs than in ridges, average velocities were less than 1 cm/s across all sites, below the typical threshold velocities needed to entrain sediment (Larsen et al., 2009). At site RS-1, water flow in the slough tended to follow the landscape orientation throughout the wet season, while flow in the ridge varied more seasonally (**Figure 6-43**). Across-site variation in water velocity was negatively related to biomass frontal area (**Figure 6-43**), reaffirming previous studies showing that biomass drives some of the spatial variation in water velocity and acts to steer water flow through sloughs.

Water Chemistry

Geometric mean TP concentrations were low throughout the DPM footprint, ranging 4 to 7 µg/L (**Figure 6-44**). There were minor spatial differences as the three DB sites tended to have greater TP concentrations than interior marsh sites and concentrations at the UB sites decreased from north to south. However, TP concentrations showed significant temporal variations with spikes in July and August 2011. These short-duration spikes in water column TP were attributed to pulses of nutrients from the underlying sediments upon reflooding, following the prior summer dryout and vegetative burn.

A considerable percentage of TP was bound in particulate form, averaging 53 percent in 2010 and 63 percent in 2011. Sites within the pocket had greater TPP values in 2011 than 2010 (**Figure 6-44**). In contrast, the DB sites had significantly greater TPP concentrations in 2010, attributable to their greater mass of suspended sediments ranging from 4.1 to 5.5 mg/L in 2010, compared to values of 0.4 to 0.7 mg/L in 2011. Sites within the pocket had typically lower suspended sediment concentrations, ranging from 0.1 to 1.2 mg/L in 2010 and 2011.

Sediment Fluxes

Average horizontal transport of sediment (per ground area) varied among the marsh sites from 4.2 kilograms per meter per year ($kg/m^2/y$) at site RS1 to 6.5 $kg/m^2/y$ at C1 (**Figure 6-45**). Transport rates in ridge and slough habitats did not show consistent differences (**Figure 6-45**), suggesting the current system does not support the redistribution of sediments from sloughs onto ridges. Temporal variation in sediment transport, on the other hand, was substantial. Transport rates were highest in November 2011, ranging from 12.0 to 15.8 $kg/m^2/yr$ (site averages) compared with lower rates observed from January to May 2012, ranging from 1.1 to 7.0 $kg/m^2/yr$. The temporal variation was attributed to higher periphyton production and faster flow during the wet season compared to the dry season. Given the temporal and spatial variability in velocities (0.07 to 0.7 cm/s) and in suspended solid concentrations (0.1 to 1.2 mg/L) observed in the pocket sites, sediment transport should be expected to vary between 0.8 to 92.7 $kg/m^2/yr$. Thus the order-of-magnitude variation in transport from sediment traps appeared consistent with hydrologic and water quality data; however, it also suggests the traps provide conservative estimates of transport.

In the L-67C canal, sediment accumulation also varied seasonally, from 1.1 kg/m^2/yr in the dry season (November 2010–June 2011, average of four sites) to 1.6 kg/m^2/yr in the wet season (June to August 2011, average of five sites). These values were similar to accumulation rates of 1 to 2 kg/m^2/yr measured from dated sediment cores in the L-28 canal in western WCA-3A (Merkel and Hickey-Vargas, 2000).

Synthesis

The landscape sediment budget illustrated in **Figure 6-45** shows an initial synthesis of the data presented above. This budget provides a means to compare the consistency between marsh sediment transport and canal accumulation data. Given an average canal accumulation rate of 1.3 kg/m^2/yr and a canal width of 12 m, the calculated sediment accumulation per meter length of canal was approximately 17.0 kg/yr. This value is three-fold higher than the expected rate if it is assumed that all canal sediments are derived from marsh sediment transport (5.5 kg/m^2/yr) (**Figure 6-45**). This discrepancy suggests there is a "missing source" of canal sediments or that the sediment traps underestimated sediment transport values. The likelihood of alternate explanations will be evaluated as additional data become available.

Significance to Water Management

The baseline information on the hydrology, water chemistry, and sediment budgets in the DPM footprint indicate that in the current state, restoration of the ridge and slough landscape patterning and microtopography is unlikely without increasing sheetflow. Water velocities were not high enough to entrain and redistribute sediments from sloughs onto ridges. In addition, marsh sediment traps indicated rates of transport were equivalent in sloughs and ridges. It is also anticipated that experimental effects of high flow on water chemistry and biogeochemical functions will be easily detectable. Surface water in the marsh and in the canal during the November–December operational period is low in TP (<10 µg/L). Small changes in TP and particulate P are likely to be detected if the high-flow impact entrains surficial sediments and in turn alters the metabolism of the periphyton and floc.

Anticipating the first high-flow impact to occur either in late 2012 or in 2013, the authors expect the entirety of the DPM data to provide critical information regarding WCA-3A decompartmentalization uncertainties, including the following:

1. How much water flow is needed to redistribute sediment from sloughs onto ridges? How far downstream from the culverts and levee gaps will the high-flow be maintained? What is the role of vegetation in shaping and attenuating water flow at the landscape scale?
2. How will increased loading of sediment and nutrients affect local biogeochemical processes such as periphyton metabolism and organic matter decomposition? What ecosystem structural and functional measurements are likely to be the key indicators of altered nutrient cycling rates, even if the water entering the system is low in TP?
3. To what extent will canals sequester and reduce the transport of sediment? To what extent will they provide high nutrient sediments? Will backfilling or partial backfilling of canals sufficiently reduce negative impacts to water quality and promote greater connectivity of marsh sediment transport?
4. How will flow affect habitat use and seasonal movements of fish? To what extent will canal fish populations be affected by canal backfill treatments?

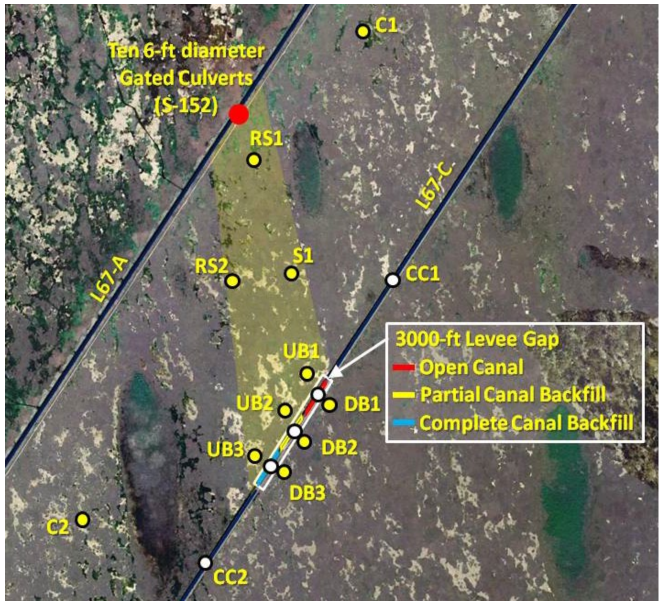

Figure 6-42. Map of the DECOMP Physical Model (DPM) experimental site located between the L67A and L67C canal/levee structures.

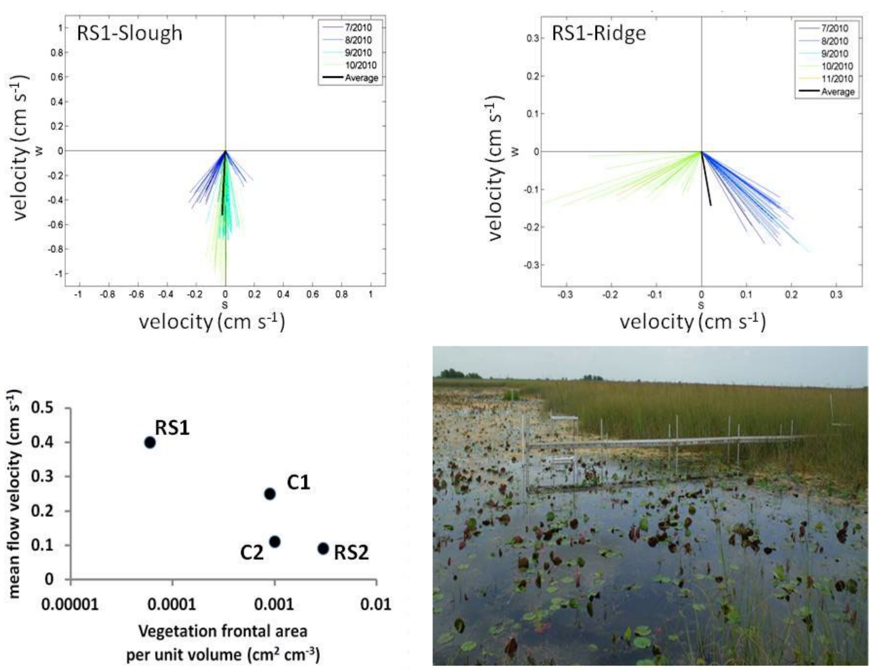

Figure 6-43. Water velocity and direction data in adjacent slough (top left) and ridge (top right) habitats at site RS-1; and cross-site variation in mean flow velocity as a function of biomass frontal area (bottom left). The RS-1 boardwalk spanning the slough and ridge shown in the photo (facing North). Acoustic Doppler Velocimeter (ADV) data are presented as daily means from July to November 2010.

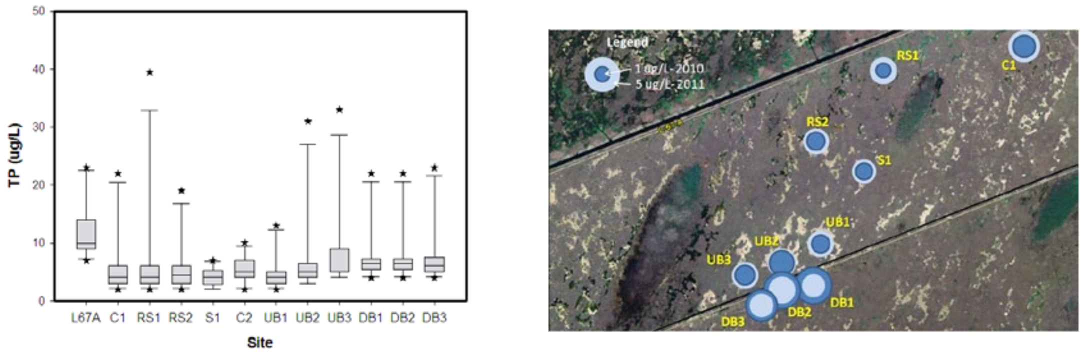

Figure 6-44. Summary of water quality parameters in the DPM. The graph is a box plot of water column TP concentrations obtained at mid-water column from slough sites within the DPM footprint. The top and bottom boundary of the box indicate the 75th and 25th percentiles, the line within the box marks the median, whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, and stars denote outliers from the 90th and 10th percentiles. The image shows the spatial and temporal distribution of total particulate phosphorus. The size of the circle indicates the total particulate phosphorus concentration while the color denotes the year; dark blue= 2010, light blue=2011.

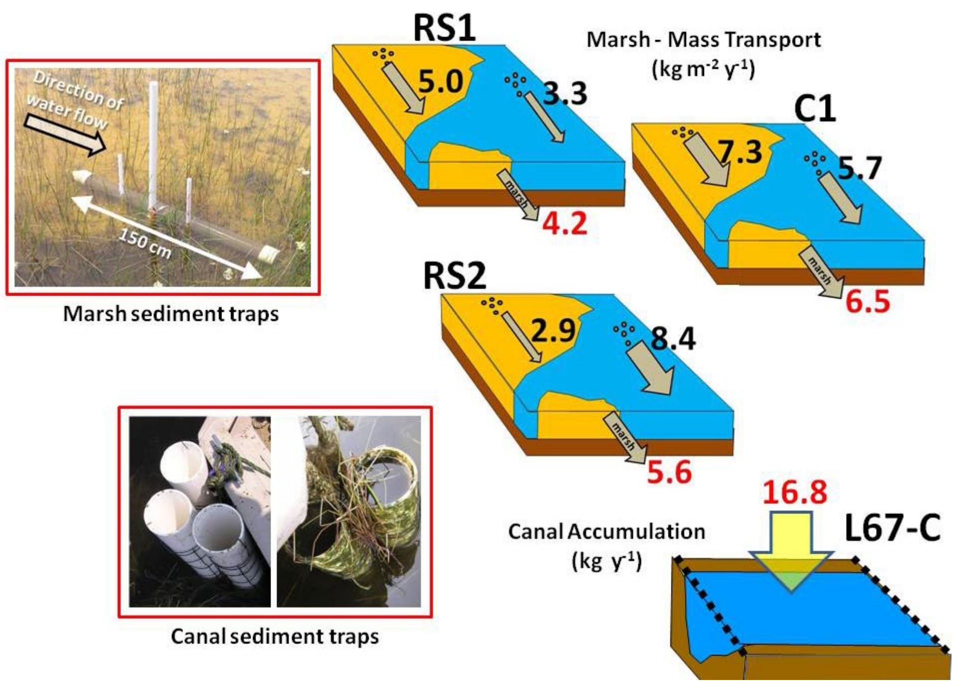

Figure 6-45. Sediment budget for marsh and canal sites, based on sediment trap data. Marsh sediment transport rates (per ground area) are average values from all deployments from November 2011 to May 2012. For marsh sites, values in red represent the average of ridge and slough values. Canal sediment accumulation rate (per meter length of canal) is the average value of all deployments from November 2010 to August 2011, multiplied by the width of the L-67C canal (12 m).

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